

(19) Japan Patent Office (JP)

(11) Japanese Unexamined Patent Application Publication Number

## (12) Japanese Unexamined Patent Application Publication (A)

11-16816

(43) Publication date: January 22, 1999

(51) Int. Cl. <sup>6</sup>	Identification Symbol	Office Reference Number	FI	Technical indication location
H01L 21/027 G03F 7/20	521	H01L 21/30 G03F 7/20 H01L 21/30		516 D 521 502G 516C

Request for examination: Not yet requested No. of claims: 5 OL (Total of 17 pages)

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(54) Title of the invention: PROJECTION EXPOSURE APPARATUS, EXPOSURE METHOD USING THE APPARATUS AND METHOD OF MANUFACTURING CIRCUIT DEVICES USING THE APPARATUS

**(57) Abstract**

Purpose: To provide a projection exposure apparatus, the projection exposure apparatus being configured such that deterioration in precision of controlling the exposure quantity is prevented, the deterioration being caused by the fluctuation in illuminance (or the fluctuation in pulse energy) on a substrate resulting from the fluctuation of the transmittance of the projection optical system.

Configuration: The quantity of ultraviolet pulse light (IL) incident on a projection optical system (PL) is measured by means of an integrator sensor (9), and the quantity of ultraviolet pulse light (IL) that has passed through the projection optical system (PL) is measured by means of an irradiation monitor (32). The quantity of transmitted light is divided by the quantity of incident light to calculate the transmittance of the projection optical system (PL). The transmittance is determined as a function of the integrated value of the quantity of incident light. During exposure, the integrated value of the quantity of incident light measured by means of the integrator sensor (9) is substituted into the function to estimate the transmissivity (transmittance) of the projection optical system (PL). The output of an excimer light source (1) is controlled according to this transmittance to control the exposure quantity.

Scope of Patent Claims

Claim 1

A projection exposure apparatus including an irradiation system in which a pattern formed in a mask is irradiated with a predetermined exposure energy beam in an ultraviolet region, and a projection optical system which projects an image of the pattern on the mask onto a substrate, comprising:

an incident energy quantity measurement system which measures incident energy quantity on the projection optical system through the mask;

an incident energy quantity integration system integrating measurement values in the incident energy quantity measurement system to obtain the quantity of the total incident energy on the projection optical system;

an emitting energy measurement system for measuring energy emitted from the projection optical system;

a transmittance characteristic storage part, which stores a variation rate in the transmittance of the projection optical system with respect to the quantity of the total incident energy on the basis of measurement results of the incident energy quantity measurement system, the incident energy quantity integration system and the emitting energy measurement system,

a computation system in which the transmittance of the projection optical system is calculated sequentially on the basis of variation rates in the transmittance stored in the transmittance characteristic storage part, and the output of the incident energy quantity integration system, and

an exposure quantity controlling system for controlling the exposure quantity of the exposure energy beam irradiated on the substrate from the irradiation system through the projection optical system according to the transmittance calculated due to the computation system.

Claim 2

The projection exposure apparatus as claimed in claim 1, wherein the transmittance characteristic storage part stores a variation rate in a transmittance of a projection optical system with respect to an elapsed time after interruption of the irradiation with the exposure energy beams, in addition to a variation rate in the transmittance of the projection optical system with respect to the quantity of the total incident energy, and the computation system calculates sequentially the transmittance of the projection optical system on the basis of two kinds of variation rates in the transmittance stored in the transmittance characteristic storage part, the output of the incident energy quantity integration system, and the elapsed time after interruption of the irradiation with the exposure energy beams.

Claim 3

The projection exposure apparatus as claimed in claim 1 or 2, further comprising:

a stage system which transfers each of the mask and the substrate;

wherein the mask and the substrate are scanned relatively through the stage system in synchronization with the projection optical system upon exposure.

Claim 4

A method of exposure using the projection exposure apparatus described in claim 3, wherein:

when the transmittance of the projection optical system is measured, the measurement values due to the incident energy quantity measurement system and the emitted energy measurement system are substituted while scanning the mask through the stage system with the reference to the projection optical system in the same manner as upon actual exposure,

the substituted measurement value is corrected with the pattern presence rate of the mask, to thereby calculate the transmittance of the projection optical system, upon exposure on the substrate, and

the exposure quantity of the exposure energy beam on the substrate is controlled on the basis of the transmittance which is corrected and obtained with the pattern presence rate of the mask.

Claim 5

A method for manufacturing a circuit device for manufacturing a predetermined circuit device using the projection exposure apparatus described in claim 1, 2 or 3, wherein the method comprises:

a first step of coating the substrate with a photosensitive material;

a second step of sequentially calculating the transmittance of the projection optical system through a computation system on the basis of variation rates in the transmittance stored in the transmittance characteristic storage part, and the output of the incident energy quantity integration system, and exposing the pattern image of the mask on a shot area of the substrate while controlling the exposure quantity of the exposure energy beam irradiated on the substrate from the irradiation system through the projection optical system according to the transmittance calculated due to the exposure quantity controlling system;

a third step of developing the substrate; and

a fourth step of forming each of the circuit patterns in each of the shot areas on the substrate after developing the substrate.

Detailed Description of the Invention

[0001]

Industrial Field of Utilization

The present invention relates to a projection exposure apparatus for use in transcribing a pattern on a mask onto a substrate through a projection optical system in a lithography process for manufacturing, for example, semiconductor elements, liquid crystal display elements, thin film magnetic heads, and so on, to an exposure method for exposure using the projection exposure apparatus, and to a method for manufacturing circuit devices by using the projection exposure apparatus.

[0002]

Prior Art

In order to respond to improvements in the degree of integration and the degree of fineness regarding semiconductor devices, there has been a demand to increase characteristics, such as resolving power and fidelity of transcription, for an exposure apparatus involved in a lithography process (representatively, consisting of a resist coating step, an exposing step, and a resist developing step) for manufacturing semiconductor devices. In order to enhance the resolving power and the fidelity of transcription, it is required to control an exposure quality with high precision for exposing a resist coated on a wafer as a substrate to light at an optimal exposure quantity.

[0003]

These days, at plants where semiconductor devices are being manufactured, a reduced projection exposure apparatus (stepper) of a step-and-repeat type using a reduced projection optical system having a 1/5-fold magnification of projection from a reticle to a wafer, which mainly uses i-rays of a 365 nm wavelength, among brilliant light rays of a mercury discharge lamp, is extensively used as exposure illumination light. Further, as a recent trend over the last few years, attention has been drawn to a reduced projection exposure apparatus of a step-and-scan type for scanning and exposing an entire image of a circuit pattern of a reticle in each region on the wafer by scanning the reticle at an equal speed in a predetermined direction in a vision field of the reduced projection optical system on its object plane side and by scanning the wafer in the corresponding direction in the vision field of the reduced projection optical system on the image plane side at a speed rate equal to a reduced magnification, in order to prevent the projection vision field of the reduced projection optical system from becoming extremely large as the size (chip size) of the circuit device to be formed on the wafer becomes larger.

[0004]

In a conventional way of controlling the exposure quality, the exposure quantity on the surface of the wafer is calculated from the light quantity of the illumination light divided in the illumination optical system and the transmittance or transmissivity thereof using the transmittance or transmissivity of the projection optical system, for example, measured at a certain point of time immediately before exposure, supposing that the transmittance or transmissivity of the projection optical system for the exposure illumination light does not fluctuate within a short time. For a conventional stepper of a step-and-scan type, the output and the scanning velocity of a light source are controlled so as to make the exposure quantity to be calculated a constant value, by controlling the exposing time so as to make an integrated value of the exposure quantity to be calculated a predetermined value.

[0005]

#### Problems to Be Solved by the Invention

Recently, in order to improve the resolving power by making the exposing wavelength shorter, projection exposure apparatuses of a step-and-repeat type and projection exposure apparatuses of a step-and-scan type have been developed, which use an ultraviolet pulse light having a wavelength of 250 nm or less from an excimer laser light source as exposure illumination light. A projection exposure apparatus using a KrF excimer laser light source having a wavelength of 248 nm has started being launched in actual manufacturing lines. Moreover, an ArF excimer laser light source emitting ultraviolet pulse light having a wavelength as short as 193 nm has been developed, and this light source is promising as a future light source for exposure.

[0006]

If such an ArF excimer laser light source is used as an exposure light source, the wavelength features of the ultraviolet pulse light are required to be narrowed to a wavelength that avoids some absorption bands of oxygen because there are such absorption bands of oxygen in a wavelength band region of the ultraviolet pulse light in its natural oscillation state. Further, it is required that the illumination light path extending from the exposure light source to the reticle and the projection light path extending from the reticle to the wafer are each brought in an environment in which oxygen is contained in the least possible amount, that is to say, that a majority of those illumination light path and projection light path is replaced with an inert gas such as nitrogen gas or helium gas. Examples of the projection exposure apparatuses using such an ArF excimer laser light source are disclosed in, for example, corresponding to Japanese Patent Application Laid-Open Nos. 6-260,385 and 6-260,386.

[0007]

There are currently known only two optical glass materials having a desired transmittance for ultraviolet pulse light (having a wavelength of about 250 nm or shorter) from the above-described excimer laser light source, which are practically applicable. They are quartz ( $\text{SiO}_2$ ) and fluorite ( $\text{CaF}_2$ ). In addition, there are known, for example, magnesium fluoride and lithium fluoride, but in order to allow them to be used as an optical glass material for use with a projection exposure apparatus, problems with, for example, processing ability and durability need to be solved.

[0008]

As a projection optical system to be loaded on a projection exposure apparatus, there may also be used a catadioptric type (a reflective-refractive system) consisting of a combination of a refractive optical element (a lens element) with a reflective optical element (particularly a concave mirror), in addition to a dioptric type (a refractive system). Whatever type of projection optical system is used, however, a refractive optical element (a transmitting optical element) has to be used, and only two kinds of optical glass materials, i.e. quartz or fluorite, can be used for a refractive optical element at the current time. Moreover, whether a refractive optical element or a reflective optical element is used, a multiple layer film such as a reflection preventive film or a protective layer for example, may be deposited on the surface of such an optical element in order to allow the resulting optical element to demonstrate improved performance to a predetermined extent as a single optical element. The performance that draws particular attention herein is how much larger the absolute value of the transmittance of a single body of the lens element or the absolute value of the reflectance or reflectivity of a single body of the reflective optical element can be made.

[0009]

For instance, for a single body of a lens element, in general, attempts have been made to make the transmittance as large as possible by coating each of the light incident plane and the light leaving plane of the lens element with a reflection preventive film or the like. Moreover, for a precise imaging optical system such as a projection optical system, as many as 20 to 30 lens elements are used for correcting a variety of aberration features to an appropriate extent. Accordingly, even in the event where the transmittance of each lens element is lowered slightly below 100%, the transmittance of the projection optical system as a whole becomes considerably low. Further, even for a projection optical system containing some reflection optical elements, the transmittance of the entire projection optical system becomes low, when the reflectance of each of the reflective optical elements is low.

[0010]

For instance, when it is supposed that the imaging light path of a projection optical system is composed of twenty-five lens elements and the transmittance of each

lens element is set to be 96%, the transmittance  $\varepsilon$  of the projection optical system as a whole becomes as low as 36% ( $0.96^{25} \times 100$ ). In cases where the transmittance of the projection optical system is low, the exposing time may become so long that a throughput may be decreased unless measures are taken to increase the intensity (energy) of illumination light for exposing the image of a circuit pattern of a reticle to a wafer or to use a resist for ultraviolet rays having a higher sensitivity. Therefore, it is considered that an excimer laser light source having a higher output is prepared as a measure that can be realized on the side of the projection optical system.

[0011]

Some exposure experiments made by a projection exposure apparatus using an excimer laser light source and having a relatively large field size reveal a new phenomenon in that the transmittance of an optical element within a projection optical system or a coating material of an optical element, including, for example, a thin film, such as a reflection preventive film or the like, fluctuates dynamically in a short time as a result of irradiation with illumination light having an ultraviolet wavelength region, such as KrF excimer laser light or ArF excimer laser light. It has further been found that this phenomenon occurs in an entirely equal manner for an optical element in the illumination optical system for illuminating a reticle or for a reticle (made of a quartz plate) itself, as well as for an optical element in a projection optical system.

[0012]

It is considered that such a phenomenon may occur due to impurities attached to the surface of an optical element or floating in the illumination light path, such impurities being contained in a gas (air, oxygen gas, etc.) present in a space within a projection light path or an illumination light path, molecules of organic substances generated from adhesive or the like for fixing an optical element to a lens barrel, or impurities (e.g., water molecules, hydrocarbon molecules, other substances diffusing the illumination light, etc.) generated from the inner wall (i.e., a coated surface for preventing the reflection of light, etc.) of a lens barrel. As a consequence, some drawbacks may occur in that the transmittance (the transmittance) of the projection optical system or the transmittance (the transmittance) of the illumination optical system fluctuates to a relatively large extent.

[0013]

For instance, if the transmittance of each lens element was lowered by 1% for the above-mentioned projection optical system being composed of twenty-five lens elements and having the transmittance  $\varepsilon$  of the entire projection optical system as low as approximately 36%, as in the manner described above, the transmittance  $\varepsilon$  of the projection optical system as a whole would become lowered to a level as low as approximately 27.7% ( $\cong 0.95^{25} \times 100$ ).

There is a risk, however, that the fluctuation of the transmittance of an optical element may vary the exposure quantity to be provided on the wafer from its optimal value and cause deterioration in the transcription fidelity of a fine pattern having a design line width as fine as approximately 0.25 to 0.18  $\mu\text{m}$  to be transcribed on the wafer. As disclosed in Japanese Patent Application Laid-Open No. 2-135723, a conventional projection exposure apparatus is configured such that the light intensity of the pulse light (an energy per pulse) from an excimer laser light source is adjusted so as to provide an optimal exposure quantity on the basis of the light intensity of the illumination light detected at a predetermined position in a light path of the illumination optical system. From this configuration, such a conventional projection exposure apparatus has a risk that the exposure quantity cannot be controlled accurately because of the fluctuation in the transmittance of the illumination optical system and the projection optical system behind the portion in the illumination light path at which the light intensity of the illumination light is being detected for controlling the exposure quantity.

[0014]

When the irradiation of the projection optical system with ultraviolet pulse light is suspended, a phenomenon is found such that the transmittance of the projection optical system recovers or fluctuates gradually. In such a case, if the exposure is resumed by starting the re-irradiation of ultraviolet pulse light, there is a risk that the accurate control of the exposure quantity becomes difficult because the transmittance of the projection optical system fluctuates. From the foregoing background, the present invention has the primary object of providing a projection exposure apparatus, the projection exposure apparatus being configured such that the deterioration in the precision of controlling the exposure quantity is prevented, the deterioration being caused by the fluctuation in illuminance (or the fluctuation in pulse energy) on a substrate resulting from a fluctuation in the transmittance of the projection optical system.

[0015]

Further, the present invention has a second object of providing an exposure method that can achieve a favorable precision in controlling the exposure quantity by using such a projection exposure apparatus. Moreover, the present invention has a third object of providing a method for manufacturing a circuit device that can form a circuit pattern on a substrate with a high fidelity of transcription by using such a projection exposure apparatus.

[0016]

#### Means to Solve Problems

A projection exposure apparatus according to the invention including an irradiation system (1 to 19) in which a pattern formed in a mask (R) is irradiated with

the predetermined exposure energy beam in an ultraviolet region, and the projection optical system (PL) which projects the image of the pattern on the mask onto the substrate (W), wherein the apparatus includes

an incident energy quantity measurement system (9) which measures the quantity of the incident energy on the projection optical system (PL) through the mask;

an incident energy quantity integration system (64) integrating measurement values in the incident energy quantity measurement system to obtain the quantity of the total incident energy on the projection optical system;

an emitting energy measurement system (32) for measuring energy emitted from the projection optical system;

a transmittance characteristic storage part (68), which stores a variation rate in a calculated transmittance of a projection optical system with respect to the quantity of the total incident energy on the basis of measurement results of the incident energy quantity measurement system (9), the incident energy quantity integration system (64) and the emitting energy measurement system (32),

a computation system (67) in which the transmittance of the projection optical system is calculated sequentially on the basis of variation rates in the transmittance stored in the transmittance characteristic storage part, and the output of the incident energy quantity integration system (64), and

an exposure quantity controlling system (1, 69; 22, 25, 27) for controlling the exposure quantity of the exposure energy beam irradiated on the substrate from the irradiation system through the projection optical system according to the transmittance calculated due to the computation system.

[0017]

According to the above-described invention, the transmittance of the projection optical system can be assumed with a high precision almost in real time by storing a variation rate in a transmittance of the projection optical system with reference to the quantity of the total incident energy on the exposure energy beam in advance, measuring the energy entering into the projection optical system from the start of exposure upon actual exposure, that is, from the start of irradiation with the exposure energy beams and substituting the variation in the transmittance of the projection optical system previously stored. Therefore, the precision of controlling the exposure quantity can be prevented from deteriorating, which may be caused by the fluctuation in illuminance (or the fluctuation in the pulse energy) on the substrate resulting from the fluctuation in the transmittance of the projection optical system by controlling the exposure quantity to offset the variation in the transmittance.

[0018]

In this case, the transmittance characteristic storage part (68) stores a variation rate in a transmittance of a projection optical system with respect to an elapsed time after interruption of the irradiation with the exposure energy beams, in addition to a variation rate in the transmittance of the projection optical system with respect to the quantity of the total incident energy, and the computation system (67) calculates the transmittance of the projection optical system sequentially on the basis of two kinds of variation rates in the transmittance stored in the transmittance characteristic storage part (68), the output of the incident energy quantity integration system (9), and the elapsed time after interruption of the irradiation with the exposure energy beams. Thereby, though the transmittance of the projection optical system is not recovered right after interruption of the irradiation with the exposure energy beam, the variation of the transmittance of the projection optical system can be assumed with a high precision.

[0019]

Further, in the apparatus including a stage system (20A, 20B, 24) which transfers each of the mask and the substrate, the mask and the substrate may be scanned relatively through the stage system in synchronization with the projection optical system upon exposure. This means that the invention is applied to a projection exposure apparatus of a scan and exposure type. In this case, the scanning velocity may also be controlled, in addition to controlling the output of an exposure light source, in order to control the exposure quantity.

[0020]

A method of exposure of the invention using the projection exposure apparatus, wherein:

when the transmittance of the projection optical system is measured, the measurement values due to the incident energy quantity measurement system (9) and the emitted energy measurement system (32) are substituted while scanning the mask through the stage system with the reference to the projection optical system in the same manner as upon actual exposure,

the substituted measurement value is corrected with the pattern presence rate (the rate of the transmittance through the pattern) of the mask, to thereby calculate the transmittance of the projection optical system, upon exposure on the substrate,

the exposure quantity of the exposure energy beam on the substrate is controlled on the basis of the transmittance which is corrected and obtained with the pattern presence rate of the mask. Thereby, an error can be prevented in measuring the transmittance of the projection optical system due to the influence of the rate of the presence of the pattern on the mask (the rate of the transmittance through the pattern) on the mask.

[0021]

Further, regarding the method for manufacturing a circuit device for manufacturing a predetermined circuit device using the projection exposure apparatus of the invention, the method includes:

a first step (step 173) of coating the substrate with a photosensitive material;  
a second step (step 174) of sequentially calculating the transmittance of the projection optical system through a computation system (68) on the basis of variation rates in the transmittance stored in the transmittance characteristic storage part (68), and the output of the incident energy quantity integration system (9), and exposing the pattern image of the mask on a shot area of the substrate while controlling the exposure quantity of the exposure energy beam irradiated on the substrate from the irradiation system through the projection optical system according to the transmittance calculated due to the exposure quantity controlling system;  
a third step (step 175) of developing the substrate; and  
a fourth step (step 176) of forming each circuit pattern in each shot area on the substrate after developing the substrate. In this case, the exposure quantity at an optimal exposure quantity is obtained in the exposing process so that the transcription fidelity of a circuit pattern is improved.

[0022]

#### Embodiments

The first embodiment of the present invention will be described below with reference to the accompanying drawings. In this example, the present invention is applied to the case where the exposing operation is carried out by using a projection optical system of a step-and-scan type. FIG. 1 shows a schematic view of the configuration of the projection optical system in this example of the present invention. As shown in FIG. 1, ultraviolet pulse light IL emitted from an ArF excimer laser light source 1, which is narrow-banded at a wavelength of 193 nm, is used as an exposure light. The ultraviolet pulse light IL is arranged so as to pass through a beam matching unit (BMU) 3, containing a movable mirror and so on, which can match the position of a light path with the main body of the projection exposure apparatus, and to enter through a light shielding pipe 5 into a variable extinction device 6 as a light attenuator. An exposure control unit 30 for controlling the exposure quantity of a resist on a wafer is configured so as to control the start and the suspension of emission of the ArF excimer laser light source 1 and an oscillation frequency thereof, and an output determined by pulse energy as well as to adjust an extinction factor of the variable extinction device 6 for ultraviolet pulse light in a stepwise or continuous manner. The present invention may also be applied to the cases where a KrF excimer laser light having a wavelength of 248 nm or laser light having another wavelength region of equal to or less than approximately 250 nm is used as an exposure light.

[0023]

The ultraviolet pulse light IL passes through the variable extinction device 6 enters into a fly's eye lens 11 through a beam shaping optical system consisting of lens systems 7A and 7B, the lens systems 7A and 7B being disposed along a predetermined light axis. Although the fly's eye lens 11 of a single stage is used in this example in the manner as described above, fly's eye lenses of two stages may also be disposed in a row as disclosed, for example, in Japanese Patent Application Laid-Open No. 1-235,289, in order to enhance the uniformity of the distribution of illuminance. On the light leaving plane of the fly's eye lens 11 is disposed an opening stop system 12 for an illumination system. In the opening stop system 12 are a circular opening stop for usual illumination, an opening stop for modified illumination consisting of plural small eccentric openings, an opening stop for annular illumination, and so on, those opening stops being disposed so as to be shifted. The ultraviolet pulse light IL leaving the fly's eye lens 11 and passing through a given opening stop in the opening stop systems 12 enters into a beam splitter 8 having a high transmittance and a low reflectance. The ultraviolet pulse light reflected by the beam splitter 8 enters into an integrator sensor 9 consisting of photoelectrical detectors, and signals detected by means of the integrator sensor 9 are transmitted to the exposure quantity control unit 30.

[0024]

The transmittance and reflectance of the beam splitter 8 are measured with high precision in advance and stored in a memory installed in the exposure quantity control unit 30. The exposure quantity control unit 30 is configured so as to monitor a light quantity of the ultraviolet pulse light IL entering into the projection optical system PL and its integrated value indirectly on the basis of the signals detected by means of the integrator sensor 9. In order to monitor the light quantity of light entering into the projection optical system PL, a beam splitter 8A may be disposed, for example, in front of the lens system 7A, as indicated by a two-digit chain line in FIG. 1, to allow a photoelectrical detector 9A to receive the reflected light reflected from the beam splitter 8A and to transmit signals detected by the photoelectrical detector 9A to the exposure quantity control unit 30.

[0025]

The ultraviolet pulse light IL transmitted through the beam splitter 8 enters into a fixed illumination vision field stop (fixed blind) 15A disposed in a reticle blind mechanism 16 through a condenser lens system 14. The fixed blind 15A has an opening portion disposed so as to extend in the form of a linear slit or in a rectangular form (hereinafter referred to collectively as "slit form") in the direction intersecting at a right angle with the scanning exposure direction in the center within a circular vision field of the projection optical system PL, as disclosed in Japanese Patent Application Laid-Open No. 4-196,513 for example. In addition, the reticle blind

mechanism 16 is provided with a movable blind 15B for changing the width of an illumination vision field region in its scanning exposure direction, separated from the fixed blind 15A, thereby reducing a stroke for scanning and transferring a reticle stage by means of the movable blind 15B and reducing the width of a light shielding band of a reticle R. The information on a rate of an opening of the movable blind 15B is transmitted to the exposure quantity control unit 30, and an actual light quantity of the light entering into the projection optical system PL is equal to a value obtained by multiplying the light quantity by the opening rate, the light quantity being obtainable from signals detected by the integrator sensor 9.

[0026]

The ultraviolet pulse light IL is shaped in a slit form by means of a fixed blind 15A of the reticle blind mechanism 16, and an illumination region on a circuit pattern region of the reticle R is irradiated with the slit-shaped ultraviolet pulse light IL at a uniform distribution of light intensity through an imaging lens system 17, a reflecting mirror 18 and a main condenser lens system 19, the illumination region being similar in shape to a slit-shaped opening portion of the fixed blind 15A. That is, the plane on which the opening portion of the fixed blind 15A or the opening portion of the movable blind 15B is disposed is constructed so as to become nearly conjugated with a pattern plane of the reticle R in association with a combination system of the imaging lens system 17 with the main condenser lens system 19.

[0027]

Upon irradiation with the ultraviolet pulse light IL, an image of the circuit pattern within the illumination region of the reticle R is transcribed onto a slit-shaped exposure region of a resist layer on a wafer W disposed on an imaging plane of the projection optical system PL at a given projection magnification  $\beta$  ( $\beta$  being 1/4 or 1/5 for example) through the projection optical system PL which is telecentric at both ends. The exposure region is located on one shot area among plural shot areas on the wafer W. The projection optical system PL for use in this example of the present invention is of a dioptric type (a refractive system), but it is needless to say that a projection optical system of a catadioptric type (a reflective-refractive system) can be used in substantially the same manner. The projection optical system PL will be described in more detail by defining the axis parallel to the light axis AX of the projection optical system PL as a Z-axis, the axis extending in the scanning direction on the flat plane, (the direction parallel to the paper plane of FIG. 1 in this example), perpendicular to the Z-axis as an X-axis, and the axis extending in the non-scanning direction intersecting at a right angle with the scanning direction (the direction perpendicular to the paper plane of FIG. 1 in this example), as a Y-axis.

[0028]

Upon irradiation with the ultraviolet pulse light IL, the reticle R is held and adsorbed on a reticle stage 20A that is loaded on a reticle base 20B so as to be movable at an equal velocity in an X-axial direction, and to be movable minutely in an X-axial direction, in a Y-axial direction, and in a rotational direction. A two-dimensional position and a rotational angle of the reticle stage 20A (reticle R) are measured on a real time basis by means of a laser interferometer disposed in a drive control unit 22. A drive motor (a linear motor, a voice coil motor for example) disposed in the drive control unit 22 is operated to control the scanning velocity and the position of the reticle stage 20A on the basis of the results of this measurement and control information from a main control system 27 consisting of a computer for managing and controlling the operation of the entire apparatus.

[0029]

On the other hand, the wafer W is held and adsorbed on a Z-tilt stage 24Z by the aid of a wafer holder WH, and the Z-tilt stage 24Z is fixed on an XY stage 24XY disposed so as to move in a two-dimensional direction along an XY plane parallel to an image plane of the projection optical system PL. A wafer stage 24 is configured of the Z-tilt stage 24Z and the XY stage 24XY. The Z-tilt stage 24Z may be configured so as to align the surface of the wafer W with the image plane of the projection optical system PL in an auto focus system and at an auto leveling system by controlling the focus position of the wafer W (the Z-axial directional position) and the angle of inclination thereof. On the other hand, the XY stage 24XY may be configured so as to scan the wafer W in the X-axial direction at an equal velocity and move it in a stepwise way in the X-axial direction and in the Y-axial direction. Moreover, the two-dimensional position and the rotational angle of the Z-tilt stage 24Z (wafer W) are measured in real time by means of a laser interferometer disposed in a drive control unit 25. A drive motor (a linear motor for example) disposed in the drive control unit 25 is operated to control the scanning velocity and the position of the XY stage 24XY on the basis of the results of this measurement and control information from the main control system 27. An error in the rotation of the wafer W can be corrected by rotating the reticle stage 20A by means of the main control system 27 and the drive control unit 22.

[0030]

The main control system 27 is configured such that a variety of information including the transfer position of each of the reticle stage 20A and the XY stage 24XY, the transferring velocity, the transferring acceleration, the position offset, and so on is transmitted to the drive control units 22 and 25. Upon scanning exposure, the reticle R is scanned in the +X-axial direction (or -X-axial direction) with respect to the illumination region of the ultraviolet pulse light IL by the aid of the reticle stage 20A at a velocity Vr. On the other hand, the wafer W is scanned in the -X-axial

direction (or +X-axial direction) with respect to the exposure region for the pattern image of the reticle R by the aid of the XY stage 24XY at a velocity  $\beta \cdot V_r$  (wherein  $\beta$  is the magnification of projection onto the wafer W from the reticle R) in synchronization with the scanning of the reticle R.

[0031]

The main control system 27 controls each blade of the movable blind 16B disposed in the reticle blind mechanism 16 so as to move in synchronization with the movement of the reticle stage 20A upon scanning exposure. Further, the main control system 27 sets a variety of exposing conditions for implementing the scanning exposure of a resist on each shot area on the wafer W at an optimal exposure quantity and executes an optimal exposure sequence even in association with the exposure quantity control unit 30. In other words, once an instruction is given from the main control system 27 to the exposure quantity control unit 30 that the scanning exposure to a one shot area on the wafer W be started, the exposure quantity control unit 30 starts emitting laser light from the ArF excimer laser light source 1 and calculating the integrated value of the entering light quantity of the light entering into the projection optical system PL through the integrator sensor 9, the integrated value being reset to zero upon the start of the scanning exposure. Then, the exposure quantity control unit 30 calculates a transmittance of the projection optical system PL from the integrated value of the entering light quantity sequentially in a manner to be described hereinafter. The output (an oscillation frequency and pulse energy) of the ArF excimer laser light source 1 and the extinction ratio of the variable extinction device 6 are controlled so as to provide an optimal exposure quantity at each point of the resist on the wafer W after the start of the scanning exposure, in accordance with the transmittance calculated. Thereafter, the emission of the ArF excimer laser light source 1 is suspended upon termination of the scanning exposure to the shot area involved.

[0032]

The irradiation monitor 32 consisting of photoelectrical detectors is disposed in the vicinity of the wafer holder WH on the Z-tile stage 24Z of this example, and the irradiation monitor 32 supplies signals detected to the exposure quantity control unit 30. The irradiation monitor 32 has a light receiving surface having a size that allows the projection optical system PL to cover the entire area of the exposure region, and it is configured such that the light quantity of the ultraviolet pulse light IL passing through the projection optical system PL can be measured by driving the XY stage 24XY and setting the light receiving surface thereof at the position at which the exposure region of the projection optical system PL is covered as a whole. In accordance with the example of the present invention, the transmittance of the projection optical system PL is measured by means of signals detected by the

integrator sensor 9 and the irradiation monitor 32. It can also be noted herein, however, that a sensor for sensing the irregularity of illuminance can be used in place of the irradiation monitor 32, the sensor having a light receiving part in the form of a pin hole for measuring the distribution of the light quantity within the exposure region.

[0033]

In the example of the present invention, in order to permit the ArF excimer laser light source 1 to be used in an appropriate way, a sub-chamber 35 may be disposed which can shield each illumination light path from open air, each illumination light path extending from the inside of the pipe 5 to the variable extinction device 6 and the lens systems 7A and 7B and from the fly's eye lens system 11 to the main condenser lens system 19. To the inside of the sub-chamber 35 as a whole is supplied dry nitrogen gas ( $N_2$ ) through a pipe 36, the nitrogen gas having the oxygen content reduced to an extremely low level. Likewise, such dry nitrogen gas is also supplied through a pipe 37 to spaces as a whole formed among plural lens elements present within a lens barrel of the projection optical system PL, i.e., spaces among the plural lens elements.

[0034]

If the sub-chamber 35 and the lens barrel of the projection optical system PL are highly airtight, it is not required to supply such dry nitrogen gas so frequently once the atmosphere therein has been completely replaced. It is necessary, however, that molecules of impurities be removed by means of a chemical filter or an electrostatic filter while flowing a temperature-controlled nitrogen gas through the light path in a forced manner, when the situation is taken into account that the transmittance is caused to fluctuate due to the attachment, etc. of impurities, such as molecules of water, hydrocarbons or the like, resulting from various substances (such as glass materials, coating materials, adhesive, paints, metals, ceramics, etc.) present in the light path, to the surfaces of the optical elements.

[0035]

Next, a description will be made of a transmittance measurement system of the projection optical system PL disposed in the projection exposure apparatus according to the example of the present invention with reference to FIG. 2. When the transmittance of the projection optical system PL is to be measured, the light receiving surface of the irradiation monitor 32 is set in the exposure region of the projection optical system PL by driving the XY stage 24XY, as shown in FIG. 2. Thereafter, the pulse emission of the ArF excimer laser light source 1 starts to emit ultraviolet pulse light IL that in turn enters onto the beam splitter 8, and a portion of the entering ultraviolet pulse light IL is reflected by the beam splitter 8 and then enters into the integrator sensor 9 as ultraviolet pulse light IL1. Together with this,

ultraviolet pulse light IL2 which has passed through the projection optical system PL enters into the irradiation monitor 32, and the signals detected by the integrator sensor 9 and the irradiation monitor 32 are incorporated into the exposure quantity control unit 30 in parallel.

[0036]

As shown in FIG. 2, the signals detected by the integrator sensor 9 as an incident energy  $E_i$  are supplied to a direct transmittance computation part 63 and an incident light quantity integration part 64 through a peak hold (P/H) circuit 61 and an analog-digital converter (ADC) 62 disposed in the exposure quantity control unit 30. In this example of the present invention, the direct transmittance computation part 63 and the incident light quantity integration part 64 as well as a transmittance computation part 67 and a control part 69, to be described hereinafter, are represented as software functions to be each executed by a microprocessor. It is a matter of course that each function can be realized by means of hardware.

[0037]

On the one hand, signals detected by the irradiation monitor 32 are fed to a direct transmittance computation part 63 as a transmittance energy  $E_o$  through a peak hold circuit 65 and an ADC 66 disposed in the exposure control unit 30, and the direct transmittance computation part 63 computes a transmittance  $T (= E_o / E_i)$  of the projection optical system PL by dividing the transmitted energy  $E_o$  by the entered energy  $E_i$ , and the transmittance  $T$  so computed is fed to the transmittance computation part 67. On the other hand, the incident light quantity integration part 64 computes a total incident energy  $e$  by integrating the incident energy  $E_i$  for every ultraviolet pulse light that enters, and the computed total incident energy  $e$  is fed to the transmittance computation part 67. The total incident energy  $e$  is reset to zero immediately before the start of the pulse emission. The transmittance computation part 67 approximates the transmittance  $T$  to be supplied by a function (e.g., a higher-order function of the second order or higher, an exponential function, etc.)  $T(e)$  of the total incident energy  $e$  supplied, and the resulting function  $T(e)$  is stored in a memory 68. Upon exposure, the transmittance computation part 67 further gives a current transmittance  $T(\text{now})$  of the projection optical system PL by substitution of the total incident energy  $e$  to be supplied from the incident light quantity integration part 64 for the function  $T(e)$  read from the memory 68 and supplies the resulting transmittance  $T(\text{now})$  to the control part 69. To the control part 69 is fed the incident energy  $E_i$  from the ADC 62, although not shown in the drawings, and the output from the ArF excimer laser light source 1 and the transmittance of the variable extinction device 6 are controlled by the control part 69 so as to adjust the exposure quantity of the ultraviolet pulse light at each point of the resist on the wafer W to an appropriate

exposure quantity by taking advantage of the incident energy  $E_i$  and the transmittance  $T$ (now).

[0038]

Next, a description will be made of the operation in accordance with the example of the present invention with reference to the flow chart as shown in FIG. 3, in which a variation in the transmittance of the projection optical system PL is measured and the scanning exposure is carried out while implementing the control over the exposure quantity on the basis of the results of this measurement. The measurement of the transmittance is carried out, for instance, at the time of starting the operation of the projection exposure apparatus or the exposure operation. First, at step 101 of FIG. 3, the light receiving surface of the irradiation monitor 32 is set in an exposing region of the projection optical system PL, as shown in FIG. 2, and the comprehensive opening rates of the fixed blind 15A and the movable blind 15B are set each to be 100%. In this example, the reticle R is detached from the reticle stage 20A, in order to give the relationship of the maximal value of the incident energy entered into the projection optical system PL with the transmittance, and no scanning by means of the reticle stage 20A is carried out. Thereafter, the pulse emission of the ArF excimer laser light source 1 is started.

[0039]

Next, at step 102, the exposure quantity control unit 30 of FIG. 2 creates an incident energy  $E_i$  corresponding to the energy actually entering into the projection optical system PL and a transmitting energy  $E_o$  corresponding to the energy actually passing through the projection optical system PL by incorporating output signals from the integrator sensor 9 and the irradiation monitor 32 in a parallel manner. Then, the incident light quantity integration part 64 as shown in FIG. 2 calculates the then total incident energy  $e$  by integrating the incident energy  $E_i$  for every pulse emission, and the direct transmittance computation part 63 calculates the transmittance  $T (=E_o/E_i)$ . This operation is being executed in a continuous way at every pulse emission until the measurement has been finished. If the exposure light is continuous light, a sample hold circuit may be used in place of the peak hold (P/H) circuit 61 and the peak hold circuit 65, and the incident light quantity integration part 64 incorporates detected signals one after another at a given sampling rate, while the direct transmittance computation part 63 calculates the transmittance  $T$  at given time intervals.

[0040]

Further, at step 103, the transmittance computation part 67 in the exposure quantity control unit 30 incorporates the total incident energy  $e$  and the transmittance  $T$  at each point of measurement time and at a measurement interval, for instance, that can become sufficiently short in respect of the exposure time for one shot. Thereafter, at step 104, it is judged whether the measurement has been finished or not. Upon this

decision, the measurement time is set in such a manner that the total incident energy  $e$  at the time of the finishing of the measurement is set so as to become sufficiently large with respect to the total incident energy to be accumulated during the exposure of one shot. The measurement time may be set to range from several seconds to several 10s of seconds. The operation of incorporating (computing) measured data by means of the transmittance computation part 67 at step 103 is repeated at given measurement intervals until a predetermined measurement time elapses, and the operation is then shifted from step 104 to step 105, as the predetermined measurement time has elapsed. Then, at step 105, the transmittance computation part 67 computes the transmittance  $T(e)$  of the projection optical system PL as a function of a series of the total incident energy  $e$  and stores the resulting transmittance  $T(e)$  in the memory 68. This storage is the equivalent of storage of a state of a variation in the transmittance of the projection optical system PL for the incident energy  $E_i$ . The function  $T(e)$  of the transmittance is used during the scanning exposure at step 109.

[0041]

Thereafter, when the scanning exposure is carried out, in the projection optical system of a step-and-scan type, the exposure quantity control is effected by controlling the scanning velocity and the light quantity of an exposure light source (including the control of the extinction rate of the variable extinction device 6), unlike the projection optical system of a step-and-repeat type. In other words, when a certain one point on the wafer is taken as an example, the scanning velocity of the wafer stage 24 and the light quantity of the exposure light source are controlled in such a manner that the certain one point is irradiated with light in a predetermined exposure quantity determined from sensitivity to the resist or the like during a period of time during which the certain point passes through the slit-shaped exposure region of the projection optical system PL.

[0042]

It is to be noted herein that a reference value of the output per unit time (i.e., an oscillating frequency  $\times$  a pulse energy) of the ArF excimer laser light source 1 is defined as  $E_o$  [W], and the output is set as a value multiplied by an extinction rate of the variable extinction device 6. Further, the initial transmittance of the projection optical system PL is set as  $T_0$ , the area of the slit-shaped exposure region is set as  $S$  [cm<sup>2</sup>], the length of the scanning direction of the exposure region is set as  $L$  [mm], and the sensitivity to the resist is set as  $I$  [J/cm<sup>2</sup>]. Under these conditions, an initial value  $Vw_0$  [mm/second] of the scanning velocity of the wafer stage 24 upon scanning exposure may be defined by the following formula.

[0043]

$$Vw_0 = (L \cdot E_o \cdot T_0) / (I \cdot S) \quad (1)$$

Immediately after the start of the scanning exposure, the scanning is effected while maintaining the relationship of the relative positions of the reticle R and the wafer W, in order to allow the wafer stage 24 to move at the scanning velocity as defined above. In other words, once the scanning exposure has been started, the reticle R is loaded on the reticle stage 20A as shown in FIG. 1 at step 106 of FIG. 3, and the wafer W coated with a resist is loaded on the wafer holder WH held on the wafer stage 24. Then, after the total incident energy e is reset to zero in the exposure quantity control unit 30, the scanning of the reticle stage 20A and the wafer stage 24 is started, and the pulse emission of the ArF excimer laser light source 1 is also started at the point of time when the scanning is brought into a synchronous state. At the same time, the incorporation of signals detected by the integrator sensor 9 into the exposure quantity control unit 30 is also started. Thereafter, as the movable blind 15B is gradually opened, and the transcription of an image of a pattern formed on the reticle R onto an involved shot area on the wafer W is started. Comprehensive information on the opening rates of the fixed blind 15A and the movable blind 15B has already been supplied to the incident light quantity integration part 64 as shown in FIG. 2.

[0044]

Then, at step 107, the incident energy  $E_i$  at every pulse emission is measured through the integrator sensor 9, the peak hold circuit 61, and the ADC 62, as shown in FIG. 2, and the measured incident energy  $E_i$  is supplied one after another to the incident light quantity integration part 64. Thereafter, at step 108, the incident light quantity integration part 64 computes the total incident energy  $e$  supplied so far by integrating the energy obtained by multiplying the incident energy  $E_i$  entered at every pulse emission by the opening rate at that time, and supplies the total incident energy  $e$  from the start of the exposure to the transmittance computation part 67. Then, at step 109, the transmittance computation part 67 calculates the current transmittance  $T(\text{now})$  of the projection optical system PL at predetermined time intervals by substituting the total incident energy  $e$  for the function  $T(e)$ , i.e., transmittance data, representative of the transmittance read from the memory 68, and supplies the calculated transmittance  $T(\text{now})$  to the control part 69. This computation may be carried out at a frequency as short as possible with respect to the exposure time for one shot. In other words, during the exposure time for one shot, the computation of the transmittance of the projection optical system PL is repeated plural times in order to obtain the current transmittance always at a nearly real time.

[0045]

Next, at step 110, the control part 69 controls the output of the ultraviolet pulse light  $IL$  on the basis of the transmittance  $T(\text{now})$  supplied. In this control, if it is assumed that the scanning velocity  $V_w$  of the wafer stage 24 does not vary from the

scanning velocity  $Vw_0$  as defined in the formula (1) above, it is such that the illuminance (energy per unit time or per area) of the ultraviolet pulse light IL on the surface (the wafer surface) of the wafer W is set to be constant, in order to make the exposure quantity at each point on the wafer W constant. In other words, it is such that the output from the ArF excimer laser light source 1 is varied so as to offset the variation in the transmittance  $T(\text{now})$  of the projection optical system PL, that is, so as to become inversely proportional to the transmittance  $T(\text{now})$ . In other words, when the value of the current transmittance  $T(\text{now})$  of the projection optical system PL at a certain time point  $t$  obtained in the manner as described above is indicated as  $T_1$ , an initial transmittance of the projection optical system PL is indicated as  $T_0$  and a reference value (an initial value) of the output of the ArF excimer laser light source 1 is indicated as  $E_0$ , a target output  $E_t$  of the ArF excimer laser light source 1 for making the illuminance of the ultraviolet pulse light IL on the wafer surface constant, the target output  $E_t$  may be obtained as follows.

[0046]

$$E_t = E_0 \times (T_0 / T_1) \quad (2)$$

Next, the control part 69 controls the output (the oscillating frequency and the pulse energy) of the ArF excimer laser light source 1 or the extinction rate of the variable extinction device 6 so as to allow the output of the ultraviolet pulse light IL passing through the variable extinction device 6 to reach the target output  $E_t$  obtained by the formula (2) above. Thereafter, when the scanning exposure is not yet finished at step 111, the operation is returned again to the processes at steps 107 to 110 to repeat the computation of the transmittance of the projection optical system PL at predetermined time intervals, the computation of the target output  $E_t$  of the ultraviolet pulse light IL, and the control of the output of the ArF excimer laser light source 1. Then, as the scanning exposure is finished, then the operation is shifted from step 111 to step 112 at which the emission from the ArF excimer laser light source 1 is suspended. After the exposure for one shot area has been finished at step 113, the exposure operation for the next shot area is started at step 114. At the time of starting the exposure for the next shot area, the computation of the transmittance of the projection optical system PL is started on the assumption that the transmittance of the projection optical system PL is recovered almost to the value equal to the initial transmittance at step 106.

[0047]

In accordance with the example of the present invention, the transmittance of the projection optical system PL is measured almost in real time on the basis of the integrated value of the incident energy entering into the projection optical system PL measured through the integrator sensor 9, and the output of the ArF excimer laser light source 1 is controlled so as to maintain the illuminance of the ultraviolet pulse

light IL on the wafer surface at a constant level on the basis of the results of measurement, so that the entire plane of each shot area on the wafer W can be exposed at an optimal exposure quantity even if the transmittance of the projection optical system PL varies.

[0048]

In the embodiment of the present invention as described above, it is to be noted herein that the output of the ArF excimer laser light source 1 is controlled in accordance with the transmittance of the projection optical system PL. As is apparent from the formula (1) above, however, the relationship can be established such that the transmittance  $T_0$  of the projection optical system PL is proportional to the scanning velocity  $V_{w0}$  of the wafer stage 24, if the output  $E_o$  of the exposure light source is constant. Therefore, in cases where the current transmittance  $T(\text{now})$  of the projection optical system PL varies, the scanning velocity of the wafer stage 24 may be controlled in proportion to the current transmittance  $T(\text{now})$  by maintaining the output of the exposure light source at a constant level. This control, however, can be conducted within the scope in which the scanning velocity does not reach its upper limit as defined by the stage system.

[0049]

Next, the second embodiment of the present invention will be described hereinafter. In this example, the projection exposure apparatus as illustrated in FIG. 1 is used, but the method for the measurement of a variation in the transmittance of the projection optical system PL is different from that used for the projection exposure apparatus of FIG. 1. Therefore, in this example a description will be made of the operation for measuring the variation in the transmittance of the projection optical system PL and the operation for implementing the scanning exposure with reference to the flow chart as illustrated in FIG. 4. In this example, a reticle R for use in actual exposure is scanned likewise upon actual exposure, when the variation in the transmittance of the projection optical system PL is to be measured. In this case, when the scanning velocity of the reticle stage 20A (reticle R) of FIG. 1 upon measurement is referred to as  $V_m$ , the output of the ArF excimer laser light source 1 upon measurement is referred to as  $E_m$ , the scanning velocity thereof upon actual scanning exposure is referred to as  $V_e$ , and the output thereof upon actual scanning exposure is referred to as  $E_e$ , the relationship can be established among those elements as follows.

[0050]

$$V_m/E_m = V_e/E_e \quad (3)$$

In other words, the total light quantity entering into the projection optical system PL during scanning the reticle R from the start of scanning to a certain optional position is made constant at the time of measurement as at the time of

scanning exposure. As a matter of course, it is desirable that the scanning velocity of the reticle stage 20A upon measurement,  $V_m$ , becomes equal to the scanning velocity thereof upon actual scanning exposure,  $V_e$ . Upon measurement, the light quantity actually entering into the projection optical system PL of FIG. 2 is set to become a light quantity obtained by multiplying the incident energy  $E_i$  measured by means of the integrator sensor 9 by a pattern transmittance of the reticle R (i.e., an area of a transmitting part within the illumination region divided by an area of an illumination region on the reticle R). On the other hand, the pattern transmittance is a value obtained by subtracting a pattern presence rate from 1. Thus, in this case, the pattern presence rate can also be used. Moreover, the transmitted energy  $E_o$  to be measured through the irradiation monitor 32 is a value obtained by multiplying the incident light quantity by the pattern transmittance of the reticle R and the transmittance of the projection optical system PL. The pattern transmittance referred to herein is known from design data of the reticle R as a function of the position X of the reticle R, and the transmittance of the projection optical system PL is an object to be provided. When the incident energy  $E_i$  to be measured through the integrator sensor 9 is referred to as  $E_i$ , the transmitted energy to be measured through the irradiation monitor 32 is referred to as  $E_o$ , the pattern transmittance of the reticle R is referred to as a function  $TR(X)$  of the position X, and the transmittance T of the projection optical system PL is referred to as T, the transmittance T of the projection optical system PL can be given from the formula as follows. More accurately, the function  $TR(X)$  of the pattern transmittance is multiplied by overall opening rates of the fixed blind 15A and the movable blind 15B.

[0051]

$$T = (1/TR(X)) \times (E_o/E_i) \quad (4)$$

Therefore, at step 121 of FIG. 4, the light receiving surface of the irradiation monitor 32 is set in the exposure region of the projection optical system PL (as shown in FIG. 2), and the reticle R is loaded on the reticle stage 20A. The reticle stage 20A is then transferred to the position from which the scanning is started. Thereafter, at step 122, the design data (reticle data) of the reticle R is called, for example, from a host computer, although not shown, by means of the main control system 27 as shown in FIG. 1, and the pattern transmittance  $TR(X)$  corresponding to the position X of the reticle R in its scanning direction is calculated. Then, at step 123, the scanning of the reticle stage 20A (reticle R) is started in response to an instruction from the main control system 27 in the same manner as upon actual exposure. At the same time, the emission of the ArF excimer laser light source 1 is started. The reticle R is then scanned in the + direction or in the -X-axial direction up to the position at which the scanning is to be finished.

[0052]

Further, at step 124, the position X of the reticle stage 20A measured through the drive control unit 22 is supplied to the main control system 27, the incident energy  $E_i$  to be measured through the integrator sensor 9 at every pulse emission is supplied to the direct transmittance computation part 63 and the incident light quantity integration part 64. Moreover, the transmitted energy  $E_o$  measured through the irradiation monitor 32 is supplied to the direct transmittance computation part 63. Then, at step 125, the main control system 27 calculates the current pattern transmittance  $TR(X)$  from the position X of the reticle stage 20A at a cycle shorter than an pulse emission cycle, and the results of calculation are supplied to the direct transmittance computation part 63 and the incident light quantity integration part 64. The incident light quantity integration part 64 calculates the total incident energy  $e$  by integrating a value obtained by multiplying the incident energy  $E_i$  at every pulse emission by the pattern transmittance  $TR(X)$ , and supplies the integrated value to the transmittance computation part 67. On the other hand, the direct transmittance computation part 63 calculates the transmittance  $T$  of the projection optical system PL by substitution of the incident energy  $E_i$  and the transmitted energy  $E_o$  for the formula (4) as indicated above, and supplies the results of computation to the transmittance computation part 67. Further, at step 126, the operation of step 125 is repeated at predetermined time intervals until the measurement is finished at step 126, that is, until the reticle R is transferred up to the position at which the scanning of the reticle R is to be finished. When the measurement has been finished, the process is moved to step 127 at which the transmittance computation part 67 gives the transmittance  $T$  of the projection optical system PL as a function  $T(e)$  of the total incident energy  $e$ . The function  $T(e)$  is then stored in the memory 68.

[0053]

Thereafter, when the actual scanning exposure is to be implemented, the scanning of the reticle R and the wafer W, as illustrated in FIG. 1, is started at step 128 in substantially the same manner as at step 106 of FIG. 3, to start the emission from the ArF excimer laser light source 1. Then, at step 129, the position X of the reticle R is measured by the drive control unit 22 at a predetermined cycle, and the incident energy  $E_i$  is measured by the integrator sensor 9 at every pulse emission. Moreover, the pattern transmittance  $TR(X)$  calculated from the position X of the reticle R is supplied to the incident light quantity integration part 64 as shown in FIG. 2, and the incident light quantity integration part 64 calculates the total incident energy  $e$  by integrating a value obtained by multiplying the incident energy  $E_i$  by the pattern transmittance  $TR(X)$ , and the results of computation are supplied to the transmittance computation part 67. At step 130, the transmittance computation part 67 computes the current transmittance  $T(\text{now})$  of the projection optical system PL by substitution of the total incident energy  $e$  for the function  $T(e)$  stored in the memory

68 at step 127 and supplies the results of computation to the control part 69. Then, in step 131, the control part 69 controls the output of the ArF excimer laser light source 1 or the extinction rate of the variable extinction device 6 so as to maintain the illuminance of the ultraviolet pulse light IL on the wafer W at a constant level by offsetting the fluctuation in the transmittance of the projection optical system PL in substantially the same manner as at step 110. Thereafter, steps 132 to 135 are executed in substantially the same manner as steps 111 to 114, respectively, to conduct the scanning exposure for the shot area and to prepare for the exposure of the next shot area.

[0054]

In accordance with this example, the pattern transmittance of the reticle is taken into account, so that the fluctuation in the transmittance of the projection optical system PL upon actual scanning exposure can be detected with higher precision. Therefore, the precision of the control of the exposure quantity can be improved. Although the reticle R is scanned in an optional direction upon measurement of the transmittance in this example, there is the risk that the form of the function  $T(e)$  representative of the transmittance of the projection optical system PL may be varied in a subtle way in the particular direction in which the reticle R is scanned. Therefore, the function  $T1(e)$  and  $T2(e)$  for the respective scanning direction may be given, and the functions  $T1(e)$  and  $T2(e)$  may be used properly in accordance with the scanning direction upon scanning exposure. This allows the exposure quantity to be controlled with high precision, for instance, in cases where the pattern transmittance of the reticle is not symmetric or where the transmittance of a substrate itself for the reticle is not symmetric.

[0055]

Now, a description will be made of the third embodiment of the present invention. In this example, too, the projection exposure apparatus as shown in FIG. 1 is used. In this example, however, the fluctuation in the transmittance of the projection optical system PL is measured even after suspension of the irradiation with the ultraviolet pulse light IL. In other words, in the first and second embodiments as described above, a variation in the transmittance of the projection optical system PL is requested simply with only the irradiation at every single scanning exposure taken into account, with the assumption that the transmittance of the projection optical system PL is returned to its initial state immediately after suspension of the irradiation with the ultraviolet pulse light IL. There is the possibility, however, that the transmittance cannot be recovered to its initial state to a sufficient extent until exposure at a next shot is to be started, after exposure at a certain one shot, depending upon the speed of recovery after suspension of the irradiation with the ultraviolet pulse light IL. In particular, in cases where a low sensitivity resist is used, the

transmittance may be varied to a large extent because a larger exposure quantity is required, so that the transmittance may become unlikely to be recovered to its initial state between shots for exposure. Further, even in cases where the stepping time between shots or other conditions are to be shortened in order to improve a throughput of the projection exposure apparatus, there is a risk that the transmittance may fail to be recovered to a sufficient extent between shots for exposure, so that it is required that the fluctuation in the transmittance after suspension of the irradiation with the ultraviolet pulse light IL be taken into consideration.

[0056]

Given the foregoing background, a description will be made of the measurement operation for measuring the variation in the transmittance of the projection optical system PL and the scanning exposure operation for performing the scanning exposure in accordance with this example of the present invention, with reference to the flow chart as shown in FIG. 5. In this example, first, at steps 141 to 145 in FIG. 5, the variation in the transmittance of the projection optical system PL is measured during the irradiation with the ultraviolet pulse light IL, the transmittance  $T(e)$  is given as a function of the total incident energy  $e$ , and the function  $T(e)$  is stored in the memory 68, in substantially the same manner as at steps 101 to 105, respectively, according to the first embodiment of the present invention as described above (or at steps 121 to 127 respectively, according to the second embodiment). Then, at steps 147 to 150, the variation in the transmittance of the projection optical system PL is measured in cases where no irradiation is performed, and the variation is represented as a function of the elapsed time.

[0057]

In other words, at step 146, the emission of the ArF excimer laser light source 1 is suspended in such a state that the projection optical system PL is irradiated with the ultraviolet pulse light IL, for example, at the exposure quantity set by adding a predetermined margin to the largest possible exposure quantity that can be assumed. Thereafter, at step 147, the elapsed time  $t$  is measured from the suspension of the emission, and the transmittance  $T(=E_o/E_i)$  of the projection optical system PL is calculated at predetermined time intervals by means of the direct transmittance computation part 63 from the transmitted energy  $E_o$  and the incident energy  $E_i$  by performing the instantaneous emission of a pulse light from the ArF excimer laser light source 1 having the lowest pulse number at step 148, as shown in FIG. 2. Then, the calculated transmittance  $T$  is supplied to the transmittance computation part 67. This measurement of the transmittance is repeated a predetermined number of times and, when the measurement is finished, the operation is shifted from step 149 to step 150. Thereafter, at step 150, the transmittance computation part 67 approximates the transmittance  $T$  of the projection optical system PL as a function  $T(t)$  of the elapsed

time  $t$  from the suspension of the emission of the ultraviolet pulse light IL and stores the function  $T(t)$  in the memory 68. As the function  $T(t)$ , there may be used various functions including a function of second order or higher order of the elapsed time  $t$  having a previously non-determined coefficient, or an exponential function.

[0058]

As shown in FIG. 6, a curved line 70C indicates an example of the variation in the transmittance  $T(=E_o/E_i)$  of the projection optical system PL after suspension of the irradiation with the ultraviolet pulse light IL. In FIG. 6, the axis of the abscissa represents the elapsed time  $t$  (in hours) elapsed from suspension of the irradiation, and the axis of the ordinate represents the transmittance  $T$  (relative value). A curved line 70A indicates the incident energy  $E_i$  (relative value) supplied instantaneously for measurement of the transmittance. A curved line 70B indicates the transmitted energy  $E_o$  (relative value) measured in correspondence with the incident energy  $E_i$ . As is apparent from the curved line 70C, the transmittance  $T$  of the projection optical system PL is lowered gradually, once it has been recovered to a great extent after suspension of the irradiation with the ultraviolet pulse light IL. The memory 68 stores the function  $T(t)$  of the elapsed time  $t$  that is obtained by approximating the curved line 70C.

[0059]

Upon performing the scanning exposure thereafter, the main control system 27 as shown in FIG. 1 supplies to the transmittance computation part 67 in FIG. 2 information indicative of the event that the ultraviolet pulse light IL is in the process of irradiating or that the irradiation with the ultraviolet pulse light IL is interrupted, for instance, due to the stepping between shots in process. Further, the transmittance computation part 67 may determine whether the ultraviolet pulse light IL is being irradiated on the basis of the presence or absence of the incident energy  $E_i$  from the ADC 62. Then, at step 151 of FIG. 5, the transmittance computation part 67 determines whether the ultraviolet pulse light IL is irradiated, and the total incident energy  $e$  from the incident light quantity integration part 64 is incorporated at predetermined time intervals at step 152 when the irradiation is in process. Further, at step 153, the current transmittance  $T(\text{now})$  of the projection optical system PL is given from this total incident energy  $e$  and the function  $T(e)$  stored in the memory 68 at step 144. Thereafter, at step 154, the output of the ultraviolet pulse light IL is controlled so as to offset the variation in the transmittance  $T(\text{now})$  in substantially the same manner as at step 110 of FIG. 3, and the operations at steps 152 to 154 are repeated until the scanning exposure is finished at step 155.

[0060]

After the scanning exposure has been finished at step 155 and the exposure of one shot area has been finished at step 159, then it is judged whether the exposure of

the whole shot areas has been finished at step 160. When it is decided that the exposure of the whole shot areas is not yet finished, then the process is returned to step 151. In this case, the wafer stage 24 is in the process of stepping in order to transfer the next shot area to the position at which the scanning is to be started and the irradiation with the ultraviolet pulse light IL is interrupted, so that the operation is shifted from step 151 to step 156 at which the transmittance computation part 67 initially calculates a current transmittance TA of the projection optical system PL from the total incident energy e supplied from the incident light quantity integration part 64 at that point of time and from the function T(e) stored at step 145. Then, the transmittance computation part 67 calculates a current transmittance TB of the projection optical system PL at step 157 from the elapsed time t elapsed so far from the interruption of the irradiation with the ultraviolet pulse light IL and from the function T(t) stored at step 150, immediately before the start of the scanning exposure of the next shot area. In this case, when the value of the transmittance T(0) when the elapsed time t is zero is set as TC, the transmittance computation part 67 calculates the current actual transmittance T(now) of the projection optical system PL at step 158 from the following formula as an example.

[0061]

$$T(\text{now}) = TA \times TB / TC \quad (5)$$

Then, as the operation is shifted from step 151 to step 152 after the start of the scanning exposure of the next shot area, the exposure quantity is controlled by setting the initial value of the transmittance of the projection optical system PL to be the value determined by the formula (5) above. The scanning exposure of each shot area is performed in the manner as described above, and the exposure operation is finished at step 161 as the exposure of the whole shot areas has been finished at step 160.

[0062]

In accordance with this example as described above, the exposure quantity to each shot area on the wafer W can be controlled with higher precision because the fluctuation in the transmittance of the projection optical system PL upon interruption of the irradiation with the ultraviolet pulse light IL between shots is also taken into consideration. Next, a description will be made of an example of the operation to be applied to the process for actually forming a circuit pattern on a wafer W by means of scanning exposure as shown in FIG. 5 with reference to the flow chart as shown in FIG. 7. First, at step 171 in FIG. 7, a reticle R is loaded on a reticle stage 20A as shown in FIG. 1. Then, at step 172, a metallic film is deposited on a wafer (wafer W) as an object to be exposed. Thereafter, at step 173, the metallic film deposited on the wafer W is coated with a resist, and the wafer W is loaded on a wafer stage 24 of the projection exposure apparatus as shown in FIG. 1. Further, at step 174, an image of a pattern formed on the reticle R is exposed to each shot area on the wafer W by

scanning and exposure, while the light quantity of the ultraviolet pulse light IL is being controlled so as to offset the variation in the transmittance of the projection optical system PL, that is, so as to maintain the illuminance of the ultraviolet pulse light IL on the wafer W at a constant level, in substantially the same manner as the operations carried out at steps 151 to 161 as shown in FIG. 5.

[0063]

Thereafter, the resist on the wafer W is developed at step 175 and the metallic film deposited on the wafer W is subjected to etching by using the resist pattern as a mask, at step 176. Then, the resist pattern is removed to form a desired circuit pattern in each shot area on the wafer W. The wafer W is then transferred to the process for forming a circuit pattern of a next layer. In this process, in this example of the present invention, the optimal exposure quantity for each shot area on the wafer W is achieved, so that the desired circuit pattern can be formed in each shot area on the wafer W with high transcription fidelity.

[0064]

It is to be noted herein that, although the above embodiments of the present invention are applied to the projection exposure apparatus of a step-and-scan type, it can also be applied to exposure with a projection exposure apparatus (stepper) of a step-and-repeat type in substantially the same manner. In the case of the stepper, however, it is preferred that the exposure time can be controlled so as to allow the integrated exposure quantity for the shot area on the wafer to reach a predetermined value, for instance, at the process corresponding to steps 110 and 111 as shown in FIG. 3.

[0065]

It has to be noted herein as a matter of course that the present invention is not to be interpreted whatsoever as being limited to the embodiments as described above and that various modifications are encompassed within the scope and spirit of this invention without departing from the gist of the invention.

[0066]

#### Effects of the Invention

The projection exposure apparatus according to the present invention is configured such that the variation in transmittance of a projection optical system is measured and stored in advance by taking advantage of the fact that the variation in the transmittance thereof demonstrates a substantially constant variation in accordance with the quantity of irradiation with light after the start of irradiation with exposure energy beams. Further, upon actual exposure, the variation in transmittance of the projection optical system is presumed from the quantity of the exposure energy beams entering into the projection optical system and the exposure quantity is controlled in accordance with the variation in the transmittance, so that the present invention offers

the advantage that deterioration in precision of controlling the exposure quantity can be prevented, such deterioration resulting from the fluctuation in illuminance or in pulse energy on a substrate, which is caused to occur due to the fluctuation in the transmittance of the projection optical system.

[0067]

Moreover, the projection exposure apparatus according to the present invention does not require the addition of a new sensor for measuring an exposure quantity on a substrate plane during exposure, so that a space in the vicinity of the stages on the substrate side does not have strict limitations applied thereto. In this case, the transmittance characteristic storage part stores a variation rate in a transmittance of a projection optical system with respect to an elapsed time after interruption of the irradiation with exposure energy beams, in addition to a variation rate in the transmittance of the projection optical system with respect to the quantity of a total incident energy. On the other hand, the computation systems can presume a variation in the transmittance of the projection optical system with a high precision, even if the transmittance of the projection optical system is not yet recovered to a sufficient level after interruption of the irradiation with exposure energy beams, when the transmittance of the projection optical system is calculated sequentially on the basis of two kinds of variation rates in the transmittance stored in the transmittance characteristic storage part, the output of the incident energy quantity integration system, and the elapsed time after interruption of the irradiation with exposure energy beams.

[0068]

Furthermore, when the present invention is applied to the projection exposure apparatus of a scanning exposure type such as a step-and-scan type, the projection exposure apparatus of such a scanning exposure type can achieve a favorable precision of controlling the exposure quantity by controlling the exposure quantity so as to provide a constant level of illuminance on the substrate plane for example, in accordance with the fluctuation in the transmittance of the projection optical system. Moreover, the exposure method according to the present invention offers the advantages that, as the transmittance of the projection optical system is measured by means of the projection exposure apparatus of a scanning exposure type according to the present invention in such a state that a mask is actually used upon measurement for the variation in the transmittance of the projection optical system, an occurrence of an error in measuring the variation in the transmittance of the projection optical system due to the fluctuation in the incident energy quantity being caused to occur on account of a difference in a density of patterns on the mask can be prevented, and precision in controlling the exposure quantity can be improved.

[0069]

In addition, the method for manufacturing the circuit device according to the present invention provides the advantage that a circuit pattern can be formed on a substrate with high transcription fidelity by using the projection exposure apparatus according to the present invention.

Brief Description of the Drawings

FIG. 1

FIG. 1 is a schematic view showing the configuration of a projection optical system for use in an embodiment of the present invention.

FIG. 2

FIG. 2 is a configuration view, including a partial functional block diagram, showing a state in which an irradiation monitor 32 is transferred into an exposure region of a projection optical system PL in order to measure a transmittance (a transmittance) of the projection optical system PL in an embodiment of the present invention.

FIG. 3

FIG. 3 is a flow chart showing the operation of measuring the transmittance of the projection optical system PL and the operation of exposure in accordance with a first embodiment of the present invention.

FIG. 4

FIG. 4 is a flow chart showing the operation of measuring the transmittance of the projection optical system PL and the operation of exposure in accordance with a second embodiment of the present invention.

FIG. 5

FIG. 5 is a flow chart showing the operation of measuring the transmittance of the projection optical system PL and the operation of exposure in accordance with a third embodiment of the present invention.

FIG. 6

FIG. 6 is a view showing an example of a variation in the transmittance of the projection optical system PL after the suspension of the irradiation with ultraviolet pulse light to be measured in the third embodiment of the present invention.

FIG. 7

FIG. 7 is a flow chart showing an example of a process for forming a circuit pattern, in accordance with the third embodiment of the present invention.

Description of Symbols

- 1 ArF excimer laser light source
- 11 fly's eye lens
- 8 beam splitter

9 integrator sensor  
16 reticle blind mechanism  
R reticle  
PL projection optical system  
W wafer  
20A reticle stage  
24 wafer stage  
27 main control system  
30 exposure control unit  
32 irradiation monitor  
63 direct transmittance computation part  
64 incident light quantity integration part  
67 transmittance computation part  
68 memory  
69 control part

FIG. 1  
RETICLE R  
MAIN CONTROL SYSTEM  
EXPOSURE CONTROL UNIT  
ArF EXCIMER LASER LIGHT SOURCE  
WAFER W  
SCANNING DIRECTION

FIG. 2  
RETICLE R  
TRANSMITTANCE COMPUTATION PART  
ArF EXCIMER LASER LIGHT SOURCE  
CONTROL PART

FIG. 3  
BEFORE EXPOSURE  
START MEASUREMENT OF TRANSMITTANCE VARIATION  
101 START IRRADIATION WITH LASER  
102 MEASURE INCIDENT ENERGY & TRANSMITTED ENERGY  
103 COMPUTE TOTAL INCIDENT ENERGY & TRANSMITTANCE OF  
OPTICAL SYSTEM  
104 MEASUREMENT FINISHED?

105 STORE TRANSMITTANCE VARIATION OF INCIDENT ENERGY

DURING EXPOSURE

START SCANNING EXPOSURE

- 106 START IRRADIATION WITH LASER
- 107 MEASURE INCIDENT ENERGY
- 108 COMPUTE TOTAL INCIDENT ENERGY FROM START OF EXPOSURE
- 109 READ TRANSMITTANCE DATA
- 110 COMPUTE TARGET LASER OUTPUT & CHANGE LASER OUTPUT
- 111 SCANNING EXPOSURE FINISHED?
- 112 STOP EMISSION OF LASER
- 113 FINISH EXPOSURE BY ONE SHOT
- 114 START EXPOSURE BY NEXT SHOT

FIG. 4

BEFORE EXPOSURE

START MEASUREMENT OF TRANSMITTANCE VARIATION

- 121 LOAD RETICLE
- 122 CALL RETICLE DATA & CALCULATE PATTERN TRANSMITTANCE CORRESPONDING TO RETICLE POSITION
- 123 SCAN RETICLE & START IRRADIATION WITH LASER
- 124 MEASURE RETICLE & POSITION, INCIDENT ENERGY & TRANSMITTED ENERGY
- 125 COMPUTE TOTAL INCIDENT ENERGY & TRANSMITTANCE OF OPTICAL SYSTEM
- 126 MEASUREMENT FINISHED?
- 127 STORE TRANSMITTANCE & VARIATION OF INCIDENT ENERGY

DURING EXPOSURE

START SCANNING EXPOSURE

- 128 START IRRADIATION WITH LASER
- 129 MEASURE RETICLE POSITION & INCIDENT ENERGY, & COMPUTE TOTAL INCIDENT ENERGY FROM START OF EXPOSURE
- 130 READ TRANSMITTANCE DATA
- 131 COMPUTE TARGET LASER OUTPUT & CHANGE LASER OUTPUT
- 132 SCANNING EXPOSURE FINISHED?
- 133 STOP EMISSION OF LASER
- 134 FINISH EXPOSURE BY ONE SHOT
- 135 START EXPOSURE BY NEXT SHOT

FIG. 5

BEFORE EXPOSURE

START MEASUREMENT OF TRANSMITTANCE VARIATION

141 START IRRADIATION WITH LASER

142 MEASURE INCIDENT ENERGY & TRANSMITTED ENERGY

143 COMPUTE TOTAL INCIDENT ENERGY & TRANSMITTANCE OF  
OPTICAL SYSTEM

144 MEASUREMENT FINISHED?

145 STORE TRANSMITTANCE VARIATION OF INCIDENT ENERGY

146 STOP EMISSION OF LASER

147 MEASURE ELAPSED TIME

148 COMPUTE TRANSMITTANCE OF OPTICAL SYSTEM BY  
INSTANTANEOUS IRRADIATION WITH LASER

149 MEASUREMENT FINISHED?

150 STORE TRANSMITTANCE VARIATION FOR SUSPENDED TIME

DURING EXPOSURE

START SCANNING EXPOSURE

151 IN IRRADIATION PROCESS

152 COMPUTE TOTAL INCIDENT ENERGY FROM START OF EXPOSURE

153 READ TRANSMITTANCE VARIATION OF INCIDENT ENERGY

154 COMPUTE TARGET LASER OUTPUT & CHANGE LASER OUTPUT

155 SCANNING EXPOSURE FINISHED?

159 FINISH EXPOSURE BY SHOT

160 EXPOSURE OF ALL SHOTS FINISHED?

161 END EXPOSURE OPERATION

156 COMPUTE TOTAL INCIDENT ENERGY FROM START OF EXPOSURE

157 READ TRANSMITTANCE VARIATION DATA FOR SUSPENDED TIME

158 RE-COMPUTE TRANSMITTANCE OF OPTICAL SYSTEM

MEASUREMENT OF TRANSMITTANCE VARIATION DURING EXPOSURE

MEASUREMENT OF TRANSMITTANCE VARIATION AFTER STOP OF

IRRADIATION

FIG. 6

TRANSMITTANCE (RELATIVE VALUE)

TIME

FIG. 7

START

171 LOAD RETICLE R ON RETICLE STAGE

172 DEPOSIT METALLIC FILM ON WAFER W

173 COAT METALLIC FILM WITH RESIST & LOAD WAFER W ON WAFER STAGE

174 EXPOSE PATTERN IMAGE OF RETICLE R TO EACH SHOT AREA OF WAFER W IN A SCANNING EXPOSURE SYSTEM WHILE CORRECTING LIGHT QUANTITY OF ULTRAVIOLET PULSE LIGHT SO AS TO OFFSET TRANSMITTANCE VARIATION OF PROJECTION SYSTEM PL

175 DEVELOP PHOTORESIST ON WAFER W

176 ETCH RESIST PATTERN ON WAFER W AS A MASK

NEXT PROCESS

(19) 日本国特許庁 (J P)

(12) 公開特許公報 (A)

(11)特許出願公開番号

特開平11-16816

(43) 公開日 平成11年(1999)1月22日

(51) Int.Cl.<sup>6</sup> 識別記号  
H 0 1 L 21/027  
G 0 3 F 7/20 521

F I		
H 0 1 L	21/30	5 1 6 D
G 0 3 F	7/20	5 2 1
H 0 1 L	21/30	5 0 2 G
		5 1 6 C

審査請求 未請求 請求項の数 5 OL (全 17 頁)

(21) 出願番号 特願平9-168406

(22) 出願日 平成9年(1997)6月25日

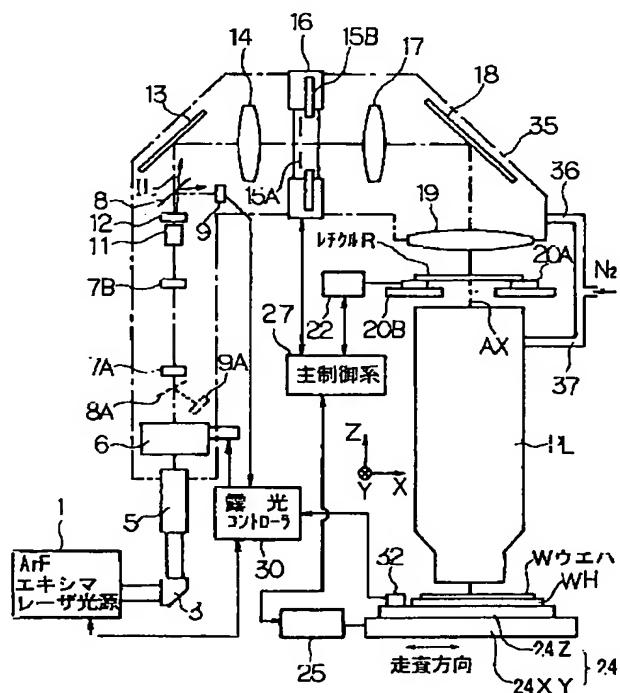
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(54) 【発明の名称】 投影露光装置、該装置を用いた露光方法、及び該装置を用いた回路デバイスの製造方法

(57)【要約】

【課題】 投影光学系の透過率変動によって発生する基板上での照度変動（又はパルスエネルギー変動）に起因した露光量の制御精度の劣化を防止した投影露光装置を提供する。

【解決手段】 投影光学系PLに入射する紫外パルス光ILの光量をインテグレータセンサ9を介して計測し、投影光学系PLを透過した紫外パルス光ILの光量を照射量モニタ32を介して計測し、透過光量を入射光量で除算することによって投影光学系PLの透過率を算出する。この透過率を入射光量の積分値の関数として求めておき、露光時にはその関数にインテグレータセンサ9を介して計測される入射光量の積分値を代入して投影光学系PLの透過率を推定し、この透過率に応じて例えばエキシマレーザ光源1の出力を制御することで露光量を制御する。



## 【特許請求の範囲】

【請求項1】 マスクに形成されたパターンを紫外域の所定の露光エネルギーービームで照射する照射系と、前記マスクのパターンの像を基板上に投影する投影光学系と、を備えた投影露光装置において、前記投影光学系に対する入射エネルギー量を計測する入射エネルギー量計測系と、該入射エネルギー量計測系の計測値を積算して前記投影光学系に対する総入射エネルギー量を求める入射エネルギー量積算系と、前記投影光学系からの射出エネルギー量を計測する射出エネルギー量計測系と、前記入射エネルギー量計測系、前記入射エネルギー量積算系、及び前記射出エネルギー量計測系の計測結果に基づいて算出される前記投影光学系の透過率の前記総入射エネルギー量に対する変化率を記憶する透過率特性記憶部と、該透過率特性記憶部に記憶されている透過率の変化率、及び前記入射エネルギー量積算系の出力に基づいて逐次前記投影光学系の透過率を算出する演算系と、該演算系によって算出される透過率に応じて前記照射系から前記投影光学系を介して前記基板上に照射される前記露光エネルギーービームの露光量を制御する露光量制御系と、を設けたことを特徴とする投影露光装置。

【請求項2】 請求項1記載の投影露光装置であって、前記透過率特性記憶部は、前記投影光学系の透過率の前記総入射エネルギー量に対する変化率の他に、前記露光エネルギーービームの照射を中断した後の経過時間に対する前記投影光学系の透過率の変化率を記憶し、前記演算系は、前記透過率特性記憶部に記憶されている透過率の2種類の変化率、前記入射エネルギー量積算系の出力、及び前記露光エネルギーービームの照射を中断した後の経過時間に基づいて逐次前記投影光学系の透過率を算出することを特徴とする投影露光装置。

【請求項3】 請求項1、又は2記載の投影露光装置であって、前記マスク及び前記基板をそれぞれ移動するステージ系を備え、露光時に前記ステージ系を介して前記マスク及び前記基板を前記投影光学系に対して相対的に同期走査することを特徴とする投影露光装置。

【請求項4】 請求項3記載の投影露光装置を用いた露光方法であって、前記投影光学系の透過率を計測する際に、前記ステージ系を介して実際の露光時と同様に前記マスクを前記投影光学系に対して走査しながら、前記入射エネルギー量計測系、及び前記射出エネルギー量計測系による計測値を取り込み、該取り込まれた計測値を前記マスクのパターン存在率で補正することによって前記投影光学系の透過率を算出し、

前記基板に対する露光時に、前記マスクのパターン存在

率で補正して得られる透過率に基づいて前記基板に対する前記露光エネルギーービームの露光量を制御することを特徴とする露光方法。

【請求項5】 請求項1、2、又は3記載の投影露光装置を用いて所定の回路デバイスを製造するための回路デバイスの製造方法であって、前記基板上に感光材料を塗布する第1工程と、前記透過率特性記憶部に記憶されている透過率の変化率、及び前記入射エネルギー量積算系の出力に基づいて前記演算系を介して逐次前記投影光学系の透過率を算出し、該算出される透過率に応じて前記露光量制御系によって前記照射系から前記投影光学系を介して前記基板上に照射される前記露光エネルギーービームの露光量を制御しながら、前記マスクのパターン像を前記基板上の各ショット領域に露光する第2工程と、前記基板の現像を行う第3工程と、該現像後の前記基板上の各ショット領域にそれぞれ回路パターンを形成する第4工程と、を有することを特徴とする回路デバイスの製造方法。

## 【発明の詳細な説明】

## 【0001】

【発明の属する技術分野】 本発明は、例えば半導体素子、液晶表示素子、又は薄膜磁気ヘッド等を製造するためのリソグラフィ工程でマスクパターンを投影光学系を介して基板上に転写するために使用される投影露光装置、この投影露光装置を用いた露光方法、及びこの投影露光装置を用いた回路デバイスの製造方法に関する。

## 【0002】

【従来の技術】 半導体デバイスの集積度及び微細度の向上に対応するため、半導体デバイスを製造するためのリソグラフィ工程（代表的にはレジスト塗布工程、露光工程、及びレジスト現像工程からなる）を担う露光装置においては、解像力、及び転写忠実度等をより高めることが要求されている。このように解像力、及び転写忠実度を高めるためには、先ず基板としてのウエハ上に塗布されたレジストを適正露光量で露光するための露光量制御を高精度に行う必要がある。

【0003】 現在、半導体デバイスの製造現場では、主に水銀放電灯の輝線のうち波長365nmのi線を露光用の照明光として、レチクルからウエハへの投影倍率が1/5倍の縮小投影光学系を用いたステップ・アンド・リピート方式の縮小投影露光装置（ステッパー）が多用されている。また、ここ数年の動向として、ウエハ上に形成される回路デバイスのサイズ（チップサイズ）の大型化に伴って縮小投影光学系の投影視野が極端に大きくなるのを避けるために、その投影光学系の物体面側の視野内でレチクルを所定方向に等速走査しつつ、その投影光学系の像面側の視野内でウエハを対応する方向に縮小倍率と同じ速度比で等速走査することで、レチクルの回路パターンの全体像をウエハ上の各領域に走査露光する

ステップ・アンド・スキャン方式の縮小投影露光装置も注目されている。

【0004】従来の露光量制御では、投影光学系の露光用の照明光に対する透過率は短時間には変動しないものとして、例えば露光直前の或る時点で計測した投影光学系の透過率を用いて、照明光学系内で分岐された照明光の光量とその透過率とからウエハの表面での露光量を計算していた。そして、ステッパーであれば、その計算される露光量の積算値が所定値となるように露光時間を制御し、ステップ・アンド・スキャン方式であれば、その計算される露光量が一定の値になるように光源の出力、又は走査速度を制御していた。

#### 【0005】

【発明が解決しようとする課題】最近では、露光波長を短波長化して解像力をより高めるために、露光用の照明光としてエキシマレーザ光源からの波長250nm程度以下の紫外パルス光を用いたステップ・アンド・リピート方式、及びステップ・アンド・スキャン方式の投影露光装置が開発され、波長248nmのKrFエキシマレーザ光源を使用した投影露光装置は製造ラインに本格的に投入され始めている。更に、より短波長の波長193nmの紫外パルス光を出力するArFエキシマレーザ光源も開発されており、これは今後の露光用光源として有望視されている。

【0006】このArFエキシマレーザ光源を露光光源として用いる場合、その紫外パルス光の自然発振状態での波長帯域内には酸素の吸収帯が幾つか存在するため、パルス光の波長特性をそれらの吸収帯を避けた波長に狭帯化することが必要となる。更に、露光光源からレチクルまでの照明光路内やレチクルからウエハまでの投影光路内に極力酸素が含まれないような環境にすること、即ちそれらの照明光路や投影光路の大部分を不活性ガス（窒素ガスやヘリウムガス等）で置換することも必要となる。そのようなArFエキシマレーザ光源を用いた投影露光装置の一例は、例えば特開平6-260385号公報、特開平6-260386号公報に開示されている。

【0007】以上のようなエキシマレーザ光源からの紫外パルス光（波長250nm程度以下）に対して所望の透過率を有する実用的な光学硝材としては、現在の所、石英(SiO<sub>2</sub>)とホタル石（萤石：CaF<sub>2</sub>）との2つが知られているだけである。もちろん、その他にフッ化マグネシウムやフッ化リチウム等も知られているが、投影露光装置用の光学硝材とするためには、加工性の問題、耐久性の問題等を解決しておく必要がある。

【0008】これに関して、投影露光装置に搭載される投影光学系としては、ジオプトリック系（屈折系）の他に、屈折光学素子（レンズ素子）と反射光学素子（特に凹面鏡）との組み合わせで構成したカタジオプトリック系（反射屈折系）も使用されている。何れのタイプの投

影光学系を採用するにしても、屈折光学素子（透過性光学素子）を使うことには変わりなく、現時点では屈折光学素子として石英とホタル石との2種類の硝材を使わざるを得ない。更に屈折光学素子にしろ反射光学素子にしろ、その表面には反射防止膜や保護層等の多層膜が蒸着され、光学素子単体としての性能が所定の状態になるよう製造されている。ここで特に注目すべき性能は、レンズ素子単体の透過率の絶対値、あるいは反射光学素子単体の反射率の絶対値がどの程度大きく取れるかである。

【0009】例えばレンズ素子単体の場合、一般に光の入射面と射出面との2面の両方に反射防止膜等をコートし、極力透過率を高めるように工夫されている。投影光学系のように精密な結像光学系においては、各種の収差特性を良好に補正するために使用するレンズ素子が20～30枚と多く、各レンズ素子の透過率が100%より僅かに低いだけで投影光学系全体の透過率はかなり小さくなる。また、幾つかの反射光学素子を含む投影光学系でも、各反射光学素子の反射率が低いときには投影光学系全体の透過率も低くなる。

【0010】例えば、投影光学系の結像光路を構成するレンズ素子が25枚の場合、それらレンズ素子の個々の透過率を96%とすると、投影光学系全体としての透過率は約36%（=0.96<sup>25</sup>×100）とかなり小さくなる。投影光学系の透過率が低い場合に、レチクルの回路パターン像をウエハ上に露光するための照明光の強度（エネルギー）の増大を図るか、又はより感度の高い紫外線用レジストを使用するかの対策を取らないと、露光時間の増大によってスループットが低下する。そこで、投影露光装置側で実現可能な対策として、より高出力なエキシマレーザ光源を用意することが考えられる。

【0011】ところが、エキシマレーザ光源を用いた比較的フィールドサイズの大きい投影露光装置によって各種の露光実験をしたところ、紫外波長域の照明光（KrFエキシマレーザ光、又はArFエキシマレーザ光等）の照射によって、短時間の間に投影光学系内の光学素子、あるいは光学素子のコート材（例えば反射防止膜等の薄膜）の透過率がダイナミックに変動するといった新たな現象が発見された。この現象は、投影光学系内の光学素子のみならず、レチクルを照明する照明光学系内の光学素子や、レチクル（石英板）自体についても全く同様に発生し得ることが分かってきた。

【0012】そのような現象は、投影光路内や照明光路内の空間に存在する気体（空気、窒素ガス等）中に含まれる不純物、光学素子を鏡筒に固定するための接着剤等から発生する有機物質の分子、或いはその鏡筒の内壁（反射防止用の塗装面等）から発生する不純物（例えば水分子、炭化水素の分子、又はこれら以外の照明光を拡散する物質）が光学素子の表面に付着したり照明光路内に進入（浮遊）することで起こるものと考えられてい

る。その結果、投影光学系の透過率や照明光学系の透過率が比較的大きく変動するといった不都合が生じる。

【0013】例えば上記のレンズ素子が25枚で透過率 $\epsilon$ が約36%の投影光学系で、レンズ素子単体の透過率が仮に一律に1%だけ低下したとすると、投影光学系全体の透過率 $\epsilon$ は約27.7% ( $\approx 0.95^{25} \times 100$ ) に低下してしまう。このような透過率の変動は、ウエハ上に与えるべき露光量を適正値から異ならせ、ウエハ上に転写される設計線幅0.25~0.18 μm程度の微細パターンの転写忠実度を劣化させる恐れがある。従来の投影露光装置では、例えば特開平2-135723号公報に開示されているように、照明光学系の光路内の所定の位置で照明光の光強度を検出し、その光強度に基づいて適正露光量が得られるようにエキシマレーザ光源からのパルス光の強度(1パルス当たりのエネルギー)を調整している。このため従来の投影露光装置では、露光量制御のために照明光の強度を検出している照明光路内の部分以降の照明光学系や投影光学系の透過率変動が全く加味されず、正確な露光量制御ができないくなる恐れがあった。

【0014】また、投影光学系に対する紫外パルス光の照射を停止した場合には、次第にその投影光学系の透過率が回復(変動)するという現象も見いだされている。このような場合に、再び紫外パルス光の照射を開始して露光を再開すると、投影光学系の透過率が変動しているため、正確な露光量制御が困難になる恐れがある。本発明は斯かる点に鑑み、投影光学系の透過率変動によって発生する基板上での照度変動(又はパルスエネルギー変動)に起因した露光量の制御精度の劣化を防止した投影露光装置を提供することを第1の目的とする。

【0015】更に本発明は、そのような投影露光装置を用いて良好な露光量制御精度が得られる露光方法を提供することを第2の目的とする。更に本発明は、そのような投影露光装置を用いて高い転写忠実度で回路パターンを基板上に形成できる回路デバイスの製造方法を提供することを第3の目的とする。

#### 【0016】

【課題を解決するための手段】本発明による投影露光装置は、マスク(R)に形成されたパターンを紫外域の所定の露光エネルギー beams で照射する照射系(1~19)と、そのマスクのパターンの像を基板(W)上に投影する投影光学系(PL)と、を備えた投影露光装置において、投影光学系(PL)に対する入射エネルギー量を計測する入射エネルギー量計測系(9)と、この入射エネルギー量計測系の計測値を積算してその投影光学系に対する総入射エネルギー量を求める入射エネルギー量積算系(64)と、その投影光学系からの射出エネルギー量を計測する射出エネルギー量計測系(32)と、入射エネルギー量計測系(9)、入射エネルギー量積算系(64)、及び射出エネルギー量計測系(32)の計測

結果に基づいて算出されるその投影光学系の透過率のその総入射エネルギー量に対する変化率を記憶する透過率特性記憶部(68)と、この透過率特性記憶部に記憶されている透過率の変化率、及び入射エネルギー量積算系(64)の出力に基づいて逐次その投影光学系の透過率を算出する演算系(67)と、この演算系によって算出される透過率に応じてその照射系からその投影光学系を介してその基板上に照射されるその露光エネルギー beams の露光量を制御する露光量制御系(1, 69; 22, 25, 27)と、を設けたものである。

【0017】斯かる本発明によれば、予め露光エネルギー beams の総入射エネルギーに対して投影光学系の透過率変化を計測して記憶しておき、実際の露光時には露光開始、即ち露光エネルギー beams の照射開始時から投影光学系に入射するエネルギーを計測しつつ、先に記憶しておいた透過率変化に当てはめることによって、ほぼリアルタイムで高精度に投影光学系の透過率が推定できる。その透過率の変動を相殺するように露光量を制御することによって、投影光学系の透過率変動によって発生する基板上での照度変動(又はパルスエネルギー変動)に起因した露光量の制御精度の劣化が防止できる。

【0018】この場合、透過率特性記憶部(68)は、その投影光学系の透過率のその総入射エネルギー量に対する変化率の他に、その露光エネルギー beams の照射を中断した後の経過時間に対するその投影光学系の透過率の変化率を記憶し、演算系(67)は、透過率特性記憶部(68)に記憶されている透過率の2種類の変化率、入射エネルギー量積算系(9)の出力、及びその露光エネルギー beams の照射を中断した後の経過時間に基づいて逐次その投影光学系の透過率を算出することが望ましい。これによって、露光エネルギー beams の照射の中断後に投影光学系の透過率がすぐに十分回復しない場合でも、高精度に投影光学系の透過率の変動を推定できる。

【0019】また、マスク及び基板をそれぞれ移動するステージ系(20A, 20B, 24)を備え、露光時にそのステージ系を介してそのマスク及びその基板をその投影光学系に対して相対的に同期走査してもよい。これは本発明を走査露光方式の投影露光装置に適用したことの意味する。この場合、露光量を制御するためには、露光光源の出力を制御する他に、走査速度を制御してもよい。

【0020】また、本発明の露光方法は、その投影露光装置を用いた露光方法であって、その投影光学系の透過率を計測する際に、そのステージ系を介して実際の露光時と同様にそのマスクをその投影光学系に対して走査しながら、入射エネルギー量計測系(9)、及び射出エネルギー量計測系(32)による計測値を取り込み、このように取り込まれた計測値をそのマスクのパターン存在率(又はパターン透過率)で補正することによってその投影光学系の透過率を算出し、その基板に対する露光時

に、そのマスクのパターン存在率で補正して得られる透過率に基づいてその基板に対するその露光エネルギーービームの露光量を制御することが望ましい。これによって、マスクのパターン存在率（パターン透過率）の影響で投影光学系の透過率が誤計測されることが防止される。

【0021】また、本発明の回路デバイスの製造方法は、本発明の投影露光装置を用いて所定の回路デバイスを製造するための回路デバイスの製造方法であって、その基板上に感光材料を塗布する第1工程（ステップ173）と、透過率特性記憶部（68）に記憶されている透過率の変化率、及び入射エネルギー量積算系（9）の出力に基づいて演算系（68）を介して逐次その投影光学系の透過率を算出し、このように算出される透過率に応じてその露光量制御系によってその照射系からその投影光学系を介してその基板上に照射されるその露光エネルギーービームの露光量を制御しながら、そのマスクのパターン像をその基板上の各ショット領域に露光する第2工程（ステップ174）と、その基板の現像を行う第3工程（ステップ175）と、この現像後のその基板上の各ショット領域にそれぞれ回路パターンを形成する第4工程（ステップ176）と、を有するものである。この場合、露光工程で適正な露光量が得られるため、回路パターンの転写忠実度が向上する。

#### 【0022】

【発明の実施の形態】以下、本発明の第1の実施の形態につき図面を参照して説明する。本例は、ステップ・アンド・スキャン方式の投影露光装置で露光を行う場合に本発明を適用したものである。図1は、本例の投影露光装置の概略構成を示し、この図1において、ArFエキシマレーザ光源1からの波長193nmで狭帯化された露光光としての紫外パルス光ILは、露光装置本体との間で光路を位置的にマッチングさせるための可動ミラー等を含むビームマッチングユニット（BMU）3を通り、遮光性のパイプ5を介して光アッテネータとしての可変減光器6に入射する。ウエハ上のレジストに対する露光量を制御するための露光制御ユニット30が、ArFエキシマレーザ光源1の発光の開始及び停止、並びに発振周波数、及びパルスエネルギーで定まる出力を制御すると共に、可変減光器6における紫外パルス光に対する減光率を段階的、又は連続的に調整する。なお、露光光としては、波長248nmのKrFエキシマレーザ光、又はその他の波長250nm程度以下のレーザ光等を使用する場合にも本発明が適用される。

【0023】可変減光器6を通った紫外パルス光ILは、所定の光軸に沿って配置されるレンズ系7A、7Bによるビーム整形光学系を経てフライアイレンズ11に入射する。このように、本例ではフライアイレンズ11は1段であるが、照度分布均一性を高めるために、例えば特開平1-235289号公報に開示されているよ

うに、フライアイレンズを直列に2段配置するようにしてもよい。フライアイレンズ11の射出面には照明系の開口絞り系12が配置されている。開口絞り系12には、通常照明用の円形の開口絞り、複数の偏心した小開口よりなる変形照明用の開口絞り、輪帯照明用の開口絞り等が切り換える自在に配置されている。フライアイレンズ11から射出されて開口絞り系12中の所定の開口絞りを通過した紫外パルス光ILは、透過率が高く反射率が低いビームスプリッタ8に入射する。ビームスプリッタ8で反射された紫外パルス光は、光電検出器よりなるインテグレータセンサ9に入射し、インテグレータセンサ9の検出信号は露光制御ユニット30に供給されている。

【0024】ビームスプリッタ8の透過率、及び反射率は予め高精度に計測されて、露光制御ユニット30内のメモリに記憶されており、露光制御ユニット30は、インテグレータセンサ9の検出信号より間接的に投影光学系PLに対する紫外パルス光ILの入射光量、及びその積分値をモニタできるように構成されている。なお、投影光学系PLに対する入射光量をモニタするためには、図1中に2点鎖線で示すように、例えばレンズ系7Aの前にビームスプリッタ8Aを配置し、このビームスプリッタ8Aからの反射光を光電検出器9Aで受光し、光電検出器9Aの検出信号を露光制御ユニット30に供給するようにしてもよい。

【0025】ビームスプリッタ8を透過した紫外パルス光ILは、コンデンサレンズ系14を経てレチクルブラインド機構16内の固定照明視野絞り（固定ブラインド）15Aに入射する。固定ブラインド15Aは、例えば特開平4-196513号公報に開示されているように、投影光学系PLの円形視野内の中央で走査露光方向と直交した方向に直線スリット状、又は矩形状（以下、まとめて「スリット状」と言う）に伸びるように配置された開口部を有する。更に、レチクルブラインド機構16内には、固定ブラインド15Aとは別に照明視野領域の走査露光方向の幅を可変とするための可動ブラインド15Bが設けられ、この可動ブラインド15Bによってレチクルステージの走査移動ストロークの低減、レチクルRの遮光帯の幅の低減を図っている。可動ブラインド15Bの開口率の情報は露光制御ユニット30にも供給され、インテグレータセンサ9の検出信号から求められる入射光量にその開口率を乗じた値が、投影光学系PLに対する実際の入射光量となる。

【0026】レチクルブラインド機構16の固定ブラインド15Aでスリット状に整形された紫外パルス光ILは、結像用レンズ系17、反射ミラー18、及び主コンデンサレンズ系19を介して、レチクルRの回路パターン領域上で固定ブラインド15Aのスリット状の開口部と相似な照明領域を一様な強度分布で照射する。即ち、固定ブラインド15Aの開口部、又は可動ブラインド1

5Bの開口部の配置面は、結像用レンズ系17と主コンデンサレンズ系19との合成系によってレチクルRのパターン面とほぼ共役となっている。

【0027】紫外パルス光ILのもとで、レチクルRの照明領域内の回路パターンの像が両側テレセントリックな投影光学系PLを介して所定の投影倍率 $\beta$ （ $\beta$ は例えば $1/4$ ,  $1/5$ 等）で、投影光学系PLの結像面に配置されたウエハW上のレジスト層のスリット状の露光領域に転写される。その露光領域は、ウエハ上の複数のショット領域のうちの1つのショット領域上に位置している。本例の投影光学系PLは、ジオプトリック系（屈折系）であるが、カタジオプトリック系（反射屈折系）も使用できることは言うまでもない。以下、投影光学系PLの光軸AXに平行にZ軸を取り、Z軸に垂直な平面内で走査方向（ここでは図1の紙面に平行な方向）にX軸を取り、走査方向に直交する非走査方向（ここでは図1の紙面に垂直な方向）にY軸を取って説明する。

【0028】このとき、レチクルRは、レチクルステージ20A上に吸着保持され、レチクルステージ20Aは、レチクルベース20B上にX方向に等速移動できると共に、X方向、Y方向、回転方向に微動できるように載置されている。レチクルステージ20A（レチクルR）の2次元的な位置、及び回転角は駆動制御ユニット22内のレーザ干渉計によってリアルタイムに計測されている。この計測結果、及び装置全体の動作を統轄制御するコンピュータよりなる主制御系27からの制御情報に基づいて、駆動制御ユニット22内の駆動モータ（リニアモータやボイスコイルモータ等）は、レチクルステージ20Aの走査速度、及び位置の制御を行う。

【0029】一方、ウエハWは、ウエハホルダWHを介してZチルトステージ24Z上に吸着保持され、Zチルトステージ24Zは、投影光学系PLの像面と平行なXY平面に沿って2次元移動するXYステージ24XY上に固定され、Zチルトステージ24Z及びXYステージ24XYよりウエハステージ24が構成されている。Zチルトステージ24Zは、ウエハWのフォーカス位置（Z方向の位置）、及び傾斜角を制御してウエハWの表面をオートフォーカス方式、及びオートレベリング方式で投影光学系PLの像面に合わせ込み、XYステージ24XYはウエハWのX方向への等速走査、及びX方向、Y方向へのステッピングを行う。Zチルトステージ24Z（ウエハW）の2次元的な位置、及び回転角は駆動制御ユニット25内のレーザ干渉計によってリアルタイムに計測されている。この計測結果及び主制御系27からの制御情報に基づいて、駆動制御ユニット25内の駆動モータ（リニアモータ等）は、XYステージ24XYの走査速度、及び位置の制御を行う。ウエハWの回転誤差は、主制御系27及び駆動制御ユニット22を介してレチクルステージ20Aを回転することで補正される。

【0030】主制御系27は、レチクルステージ20

A、及びXYステージ24XYのそれぞれの移動位置、移動速度、移動加速度、位置オフセット等の各種情報を駆動制御ユニット22及び25に送る。そして、走査露光時には、レチクルステージ20Aを介して紫外パルス光ILの照明領域に対してレチクルRが+X方向（又は-X方向）に速度Vrで走査されるのに同期して、XYステージ24XYを介してレチクルRのパターン像の露光領域に対してウエハWが-X方向（又は+X方向）に速度 $\beta \cdot Vr$ （ $\beta$ はレチクルRからウエハWへの投影倍率）で走査される。

【0031】また、主制御系27は、上述のレチクルブラインド機構16内に設けられている可動ブラインド16Bの各ブレードの移動を走査露光時のレチクルステージ20Aの移動と同期するための制御を行う。更に主制御系27は、ウエハW上の各ショット領域のレジストを適正露光量で走査露光するための各種露光条件を設定して、露光制御ユニット30とも連携して最適な露光シーケンスを実行する。即ち、ウエハW上の1つのショット領域への走査露光開始の指令が主制御系27から露光制御ユニット30に発せられると、露光制御ユニット30はArFエキシマレーザ光源1の発光を開始すると共に、インテグレータセンサ9を介して投影光学系PLに対する入射光量の積分値を算出する。その積分値は走査露光開始時に0にリセットされている。そして、露光制御ユニット30では、後述のようにその入射光量の積分値より投影光学系PLの透過率を逐次算出し、この透過率に応じて、走査露光後のウエハW上のレジストの各点で適正露光量が得られるように、ArFエキシマレーザ光源1の出力（発振周波数、及びパルスエネルギー）及び可変減光器6の減光率を制御する。そして、当該ショット領域への走査露光の終了時に、ArFエキシマレーザ光源1の発光が停止される。

【0032】また、本例のZチルトステージ24Z上のウエハホルダWHの近傍には光電検出器よりなる照射量モニタ32が設置され、照射量モニタ32の検出信号も露光制御ユニット30に供給されている。照射量モニタ32は、投影光学系PLによる露光領域の全体を覆う大きさの受光面を備え、XYステージ24XYを駆動してその受光面を投影光学系PLの露光領域を覆う位置に設定することで、投影光学系PLを通過した紫外パルス光ILの光量を計測できる。本例では、インテグレータセンサ9及び照射量モニタ32の検出信号を用いて投影光学系PLの透過率を計測する。なお、照射量モニタ32の代わりに、その露光領域内での光量分布を計測するためのピンホール状の受光部を有する照度むらセンサを使用してもよい。

【0033】本例ではArFエキシマレーザ光源1を用いているため、パイプ5内から可変減光器6、レンズ系7A, 7B、更にフライアイレンズ11～主コンデンサレンズ系19までの各照明光路を外気から遮断するサブ

チャンバ35が設けられ、そのサブチャンバ35内の全体には配管36を通して酸素含有率を極めて低く抑えた乾燥窒素ガス( $N_2$ )が供給される。同様に、投影光学系PLの鏡筒内部の空間(複数のレンズ素子間の空間)の全体にも配管37を介して乾燥窒素ガスが供給される。

【0034】その乾燥窒素ガスの供給は、サブチャンバ35や投影光学系PLの鏡筒の気密性が高い場合は、一度大気との完全な置換が行われた後はそれ程頻繁に行う必要はない。しかしながら、光路内に存在する各種の物質(硝材、コート材、接着剤、塗料、金属、セラミックス等)から生じる水分子や炭化水素分子等が光学素子の表面に付着して起こる透過率変動を考慮すると、温度制御された窒素ガスを光路内で強制的にフローさせつつ、ケミカルフィルタや静電フィルタによってそれらの不純物分子を除去していくことも必要である。

【0035】次に、本例の投影露光装置における投影光学系PLの透過率計測系につき図2を参照して説明する。投影光学系PLの透過率計測を行う場合には、図2に示すように、XYステージ24XYを駆動して照射量モニタ32の受光面が投影光学系PLの露光領域に設定される。そして、ArFエキシマレーザ光源1のパルス発光が開始されて、ビームスプリッタ8に入射する紫外パルス光ILの一部が反射されて、紫外パルス光IL1としてインテグレータセンサ9に入射する。これと共に、投影光学系PLを通過した紫外パルス光IL2は、照射量モニタ32に入射し、インテグレータセンサ9の検出信号、及び照射量モニタ32の検出信号は並列に露光制御ユニット30に取り込まれる。

【0036】図2において、インテグレータセンサ9の検出信号は、露光制御ユニット30内でピークホールド(P/H)回路61、及びアナログ・デジタル変換器(以下、「ADC」と呼ぶ)62を介して入射エネルギーEiとして直接透過率計算部63、及び入射光量積分部64に供給されている。直接透過率計算部63、入射光量積分部64、及び後述の透過率演算部67、制御部69は、本例ではそれぞれマイクロプロセッサによって実行されるソフトウェア上の機能を表すものであるが、それらの機能をそれぞれハードウェアで実現してもよいことは言うまでもない。

【0037】一方、照射量モニタ32の検出信号は、露光制御ユニット30内でピークホールド回路65、及びADC66を介して透過エネルギーEoとして直接透過率計算部63に供給されている。直接透過率計算部63では、透過エネルギーEoを入射エネルギーEiで除算して投影光学系PLの透過率T( $=Eo/Ei$ )を算出し、算出した透過率Tを透過率演算部67に供給する。また、入射光量積分部64では、入射する紫外パルス光毎に入射エネルギーEiを積分(積算)して入射総エネルギーeを算出し、算出した入射総エネルギーeを透過率演算部67に供給する。入射総エネルギーeは、パル

ス発光の開始直前に0にリセットされている。透過率演算部67は、供給される透過率Tを供給される入射総エネルギーeの関数(2次以上の高次関数、又は指数関数等)T(e)で近似し、この関数T(e)をメモリ68に格納する。そして、露光時に透過率演算部67は、入射光量積分部64から供給される入射総エネルギーeをそのメモリ68から読み出された関数T(e)に代入することによって現在の投影光学系PLの透過率T(now)を求める。この透過率T(now)を制御部69に供給する。不図示であるが、制御部69には、ADC62からの入射エネルギーEiも供給されており、制御部69では、その入射エネルギーEi、及び透過率T(now)を用いてウエハW上のレジストの各点での紫外パルス光の露光量が適正露光量となるようにArFエキシマレーザ光源1の出力、及び可変減光器6における減光率を制御する。

【0038】次に、本例において投影光学系PLの透過率の変化を計測し、その計測結果に基づいて露光量制御を行いながら走査露光を行う場合の動作につき、図3のフローチャートを参照して説明する。その透過率の計測は、例えば投影露光装置の稼働開始時や露光動作開始時等に行われる。先ず、図3のステップ101において、図2に示すように、照射量モニタ32の受光面が投影光学系PLの露光領域に設定され、固定ブラインド15A及び可動ブラインド15Bの総合的な開口率が100%に設定される。この例では、投影光学系PLに対する入射エネルギーの最大値と透過率との関係を求めるのが目的であるため、レチクルRがレチクルステージ20Aから取り外され、レチクルステージ20Aの走査も行われない。そして、ArFエキシマレーザ光源1のパルス発光が開始される。

【0039】それに続くステップ102において、図2の露光制御ユニット30ではインテグレータセンサ9及び照射量モニタ32の出力信号を並列に取り込むことによって、投影光学系PLに実際に入射するエネルギーに対応する入射エネルギーEi、及び投影光学系PLを実際に通過するエネルギーに対応する透過エネルギーEoが生成される。そして、パルス発光毎に、図2の入射光量積分部64では、入射エネルギーEiを積分してそれまでの入射総エネルギーeを算出し、直接透過率計算部63では透過率T( $=Eo/Ei$ )を算出する。この動作は計測終了までパルス発光毎に連続的に実行される。なお、露光光が連続光であれば、ピークホールド回路61、65の変わりにサンプルホールド回路を使用して、入射光量積分部64では検出信号を所定のサンプリングレートで順次積算すればよく、直接透過率計算部63では所定の時間間隔で透過率Tを算出すればよい。

【0040】次に、ステップ103において、露光制御ユニット30内の透過率演算部67では、例えば1ショットの露光時間に対して十分短い間隔になるような計測

間隔で、各計測時点での入射総エネルギー  $e$ 、及び透過率  $T$  を取り込む。次のステップ104では、計測終了かどうかが判定されるが、計測終了時の入射総エネルギー  $e$  が1ショットの露光の間に蓄積される入射総エネルギー  $e$  に対して十分大きくなるように計測時間が設定されている。計測時間は、一例として数sec～数10secである。そして、ステップ103の透過率演算部67による計測データの取り込み動作（計算動作）を所定の計測間隔で繰り返して、所定の計測時間が経過した後、動作はステップ104からステップ105に移行して、透過率演算部67では、一連の入射総エネルギー  $e$  の関数として投影光学系PLの透過率  $T(e)$  を求めてメモリ68に格納する。これは、入射エネルギー  $E_i$  に対する投影光学系PLの透過率変化の状態を記憶するのと等価である。その透過率の関数  $T(e)$  は走査露光中のステップ109で使用される。

【0041】その後、走査露光を行う場合、ステップ・アンド・スキャン方式の投影露光装置ではステップ・アンド・リピート方式とは異なり、露光量制御を走査速度と露光光源の光量制御（可変減光器6の減光率制御を含む）との両方を用いて行なうことが行われる。即ち、ウエハ上の1点について考えると、その点が投影光学系PLによるスリット状の露光領域を通過する時間中に、レジスト感度等から定まる所定の露光量がその点に対して照射されるようにウエハステージ24の走査速度及び露光光源の光量を制御する。

【0042】ここで、ArFエキシマレーザ光源1の単位時間当たりの出力（即ち、発振周波数×パルスエネルギー）の基準値を  $E_0$  [W] とする。更に、以下ではその出力は可変減光器6での減光率を乗じた値とする。そして、投影光学系PLの初期透過率を  $T_0$ 、スリット状の露光領域の面積を  $S$  [cm<sup>2</sup>]、その露光領域の走査方向の長さを  $L$  [mm]、レジスト感度を  $I$  [J/cm<sup>2</sup>] とすると、走査露光時のウエハステージ24の走査速度の初期値  $Vw_0$  [mm/sec] は、次のようになる。

【0043】

$$Vw_0 = (L \cdot E_0 \cdot T_0) / (I \cdot S) \quad (1)$$

走査露光開始直後には、ウエハステージ24がその走査速度となるように、レチクルRとウエハWとの相対的な位置関係を維持しつつ走査が行われる。即ち、走査露光が開始されると、図3のステップ106において、図1に示すようにレチクルステージ20A上にレチクルRが載置され、ウエハステージ24上のウエハホルダWHにレジストが塗布されたウエハWがロードされる。そして、露光制御ユニット30内で入射総エネルギー  $e$  が0にリセットされた後、レチクルステージ20A及びウエハステージ24の走査が開始され、走査の同期が取られた時点でArFエキシマレーザ光源1のパルス発光が開始され、インテグレータセンサ9の検出信号の露光制御

ユニット30への取り込みも開始される。その後、次第に可動ブラインド15Bが開いてレチクルRのパターン像のウエハW上の当該ショット領域への転写が開始される。固定ブラインド15A、及び可動ブラインド15Bの総合的な開口率の情報は、図2の入射光量積分部64に供給されている。

【0044】そして、ステップ107において、パルス発光毎に図2のインテグレータセンサ9、ピークホールド回路61、及びADC62を介して入射エネルギー  $E_i$  が計測され、この入射エネルギー  $E_i$  が順次入射光量積分部64に供給される。それに続くステップ108において、入射光量積分部64では、パルス発光毎に供給される入射エネルギー  $E_i$  にそのときの開口率を乗じて得られるエネルギーを積算してそれまでの入射総エネルギー  $e$  を求め、この露光開始からの入射総エネルギー  $e$  を透過率演算部67に供給する。次のステップ109において、透過率演算部67では、メモリ68から読み出した透過率を表す関数  $T(e)$ （即ち、透過率データ）にその入射総エネルギー  $e$  を代入して、所定の時間間隔で現在の投影光学系PLの透過率  $T(now)$  を算出し、算出した透過率  $T(now)$  を制御部69に供給する。この計算の頻度は、1ショットの露光時間に対して十分短くなるようにする。即ち、1ショットの露光時間中において、複数回にわたって投影光学系PLの透過率計算を繰り返し、常にほぼリアルタイムで現時点での透過率を求めるようとする。

【0045】次のステップ110で、制御部69は、供給された透過率  $T(now)$  に基づいて紫外パルス光ILの出力を制御する。ここでは、ウエハステージ24の走査速度  $Vw$  を（1）式の  $Vw_0$  から変化させないものとすると、ウエハW上の各点での露光量を一定にするためには、紫外パルス光ILのウエハWの表面（ウエハ面）での照度（単位時間当たり、単位面積当たりのエネルギー）を一定にすればよい。即ち、投影光学系PLの透過率  $T(now)$  の変化を相殺するように（その透過率  $T(now)$  に反比例させて）、ArFエキシマレーザ光源1の出力を変化させればよい。具体的に、そのようにして求めた或る時点における投影光学系PLの透過率  $T(now)$  の値を  $T_1$ 、投影光学系PLの初期透過率を  $T_0$ 、ArFエキシマレーザ光源1の出力の基準値（初期値）を  $E_0$  として、ウエハ面での紫外パルス光ILの照度を一定にするためのArFエキシマレーザ光源1の目標出力を  $E_t$  とすると、 $E_t$  は以下のように求められる。

$$E_t = E_0 \times (T_0 / T_1) \quad (2)$$

そこで、制御部69は、可変減光器6を通過する紫外パルス光ILの出力が（2）式より求めた目標出力  $E_t$  となるように、ArFエキシマレーザ光源1の出力（発振周波数、及びパルスエネルギー）、又は可変減光器6での減光率を制御する。次に、ステップ111で走査露光

が終了していないときには、動作は再びステップ107～110に戻って所定の時間間隔で投影光学系PLの透過率の計算、紫外パルス光ILの目標出力E<sub>t</sub>の計算、及びArFエキシマレーザ光源1の出力制御が行われる。そして、走査露光が終了したときには、動作はステップ111からステップ112に移行して、ArFエキシマレーザ光源1の発光が停止され、1ショット分の露光が終了した後（ステップ113）、次のショット領域への露光動作が開始される（ステップ114）。次のショット領域の露光開始時には、投影光学系PLの透過率はステップ106での初期透過率にほぼ回復しているものとして透過率の計算が開始される。

【0047】このように本例によれば、インテグレータセンサ9を介して計測される投影光学系PLへの入射エネルギーの積分値に基づいて投影光学系PLの透過率をほぼリアルタイムで計測し、この計測結果に基づいてウエハ面での紫外パルス光ILの照度が一定になるようにArFエキシマレーザ光源1の出力を制御しているため、投影光学系PLの透過率が変化する場合でもウエハW上の各ショット領域の全面を適正露光量で露光できる。

【0048】なお、上述の実施の形態では、投影光学系PLの透過率に応じてArFエキシマレーザ光源1の出力を制御しているが、（1）式より分かるように、露光光源の出力E<sub>t</sub>が一定であれば、投影光学系PLの透過率T<sub>0</sub>とウエハステージ24の走査速度V<sub>w</sub>とは比例する関係にある。そこで、投影光学系PLの透過率T<sub>(n o w)</sub>が変化した場合には、露光光源の出力を一定にしておいて、透過率T<sub>(n o w)</sub>に比例してウエハステージ24の走査速度を制御してもよい。但し、この制御は、走査速度がステージ系で定まる上限に達しない範囲で行うことができる。

【0049】次に、本発明の第2の実施の形態につき説明する。本例でも図1の投影露光装置を使用するが、投影光学系PLの透過率の変化の計測方法が異なっている。そこで、本例における投影光学系PLの透過率の変化の計測動作、及び走査露光動作につき、図4のフローチャートを参照して説明する。本例では投影光学系PLの透過率変化を計測する際に、実際に露光するレチクルRを使用してこれを実際の露光時と同様に走査させる。この計測の際の図1のレチクルステージ20A（レチクルR）の走査速度をV<sub>a</sub>、ArFエキシマレーザ光源1の出力をE<sub>a</sub>として、それらの実際の走査露光時の走査速度をV<sub>e</sub>、出力をE<sub>e</sub>とすると、これらの間には以下の関係が成り立つようになる。

$$V_a / E_a = V_e / E_e \quad (3)$$

即ち、走査開始から或る任意の位置までレチクルRを走査する間に投影光学系PLに入射する総光量が、計測時と走査露光時とで同一になるようにする。当然ながら、V<sub>a</sub> = V<sub>e</sub>となるのが望ましい。なお、この計測の際、

図2の投影光学系PLに実際に入射する光量は、インテグレータセンサ9で計測される入射エネルギーE<sub>i</sub>にレチクルRのパターン透過率（=照明領域内の透過部の面積/レチクルR上の照明領域の面積）を掛け合わせた光量である。なお、パターン透過率は1からパターン存在率を差し引いた値でもあるため、このパターン存在率を使用してもよい。また、照射量モニタ32を介して計測される透過エネルギーE<sub>o</sub>は、入射する光量にレチクルRのパターン透過率と、投影光学系PLの透過率とを掛け合わせたものとなる。ここで、パターン透過率はレチクルRの設計データよりレチクルRの位置Xの関数として既知であり、求める対象は投影光学系PLの透過率である。そこで、インテグレータセンサ9を介して計測される入射エネルギーE<sub>i</sub>、照射量モニタ32を介して計測される透過エネルギーE<sub>o</sub>を用いて、レチクルRのパターン透過率を位置Xの関数TR(X)、投影光学系PLの透過率をTとすれば、以下の式より投影光学系PLの透過率Tが求まる。より正確には、そのパターン透過率の関数TR(X)には、固定ブラインド15A及び可動ブラインド15Bの総合的な開口率が乗じられている。

#### 【0051】

$$T = (1 / TR(X)) \times (E_o / E_i) \quad (4)$$

そこで、先ず図4のステップ121において、図2に示すように、投影光学系PLの露光領域に照射量モニタ32の受光面が設定され、レチクルステージ20A上にレチクルRが載置され、レチクルステージ20Aは走査開始位置に移動する。次のステップ122において、図1の主制御系27によって例えば不図示のホストコンピュータよりレチクルRの設計データ（レチクルデータ）が呼び出され、レチクルRの走査方向の位置Xに対応するパターン透過率TR(X)が算出される。その後、ステップ123において、主制御系27の指令によって実際の露光時と同様にレチクルステージ20A（レチクルR）の走査が開始され、ArFエキシマレーザ光源1の発光も開始される。レチクルRは+方向、又は-X方向に走査終了位置まで走査される。

【0052】そして、ステップ124で、駆動制御ユニット22を介して計測されたレチクルステージ20Aの位置Xが主制御系27に供給され、パルス発光毎にインテグレータセンサ9を介して計測される入射エネルギーE<sub>i</sub>が直接透過率計算部63、及び入射光量積分部64に供給され、照射量モニタ32を介して計測される透過エネルギーE<sub>o</sub>が直接透過率計算部63に供給される。次のステップ125において、主制御系27は、レチクルステージ20Aの位置Xよりパルス発光の周期より短い周期で現在のパターン透過率TR(X)を算出し、算出結果を直接透過率計算部63、及び入射光量積分部64に供給する。入射光量積分部64では、パルス発光毎に入射エネルギーE<sub>i</sub>にそのパターン透過率TR(X)

を乗じた値を積分（積算）して入射総エネルギー $e$ を算出して透過率演算部67に供給し、直接透過率計算部63では、入射エネルギー $E_i$ 、及び透過エネルギー $E_o$ を（4）式に代入して投影光学系PLの透過率 $T$ を計算し、計算結果を透過率演算部67に供給する。次のステップ126で計測終了となるまで、即ちレチクルRが走査終了位置まで移動するまで、所定の時間間隔でステップ125の動作が繰り返され、計測が終了したときにステップ127に移行して、透過率演算部67では、投影光学系PLの透過率 $T$ を入射総エネルギー $e$ の関数 $T(e)$ として求め、この関数 $T(e)$ をメモリ68に格納する。

【0053】その後、実際に走査露光を行う場合には、ステップ128において、図3のステップ106と同様に、図1に示すようにレチクルR及びウエハWの走査が開始されて、ArFエキシマレーザ光源1の発光が開始される。そして、ステップ129において、所定周期で駆動制御ユニット22によりレチクルRの位置Xの計測が行われ、パルス発光毎にインテグレータセンサ9による入射エネルギー $E_i$ の計測が行われる。そして、レチクルRの位置Xより算出されるパターン透過率 $T_R(X)$ が図2の入射光量積分部64に供給され、入射光量積分部64は入射エネルギー $E_i$ にそのパターン透過率 $T_R(X)$ を乗じた値を積分して入射総エネルギー $e$ を計算し、計算結果を透過率演算部67に供給する。ステップ130において、透過率演算部67では、ステップ127でメモリ68に記憶された関数 $T(e)$ にその入射総エネルギー $e$ を代入して現在の投影光学系PLの透過率 $T(now)$ を算出し、算出結果を制御部69に供給する。そして、制御部69では、ステップ131において、ステップ110と同様に投影光学系PLの透過率の変動を相殺してウエハW上での紫外パルス光ILの照度が一定となるように、ArFエキシマレーザ光源1の出力、又は可変減光器6の減光率を制御する。その後のステップ132～135はステップ111～114と同様であり、当該ショット領域への走査露光、及び次のショット領域への露光準備が行われる。

【0054】この例によれば、レチクルのパターン透過率も考慮しているため、実際の走査露光時の投影光学系PLの透過率の変動をより高精度に検出できる。従って、露光量の制御精度も向上している。なお、上記の例では透過率計測時にはレチクルRは任意の方向に走査されるものとしているが、走査方向によって投影光学系PLの透過率を表す関数 $T(e)$ の形が微妙に変化する恐れもある。そこで、走査方向毎にその関数 $T_1(e)$ 、 $T_2(e)$ を求めておき、走査露光時には走査方向に応じてその関数 $T_1(e)$ 、 $T_2(e)$ を使い分けるようにしてもよい。これによって、レチクルのパターン透過率が対称でない場合や、レチクルの基板自体の透過率が対称でない場合等にも、高精度に露光量制御が行われる。

る。

【0055】次に、本発明の第3の実施の形態につき説明する。本例でも図1の投影露光装置を使用するが、本例では紫外パルス光ILの照射停止後の投影光学系PLの透過率の変動をも計測する。即ち、上記の第1及び第2の実施の形態においては、投影光学系PLの透過率が紫外パルス光ILの照射停止後に直ちに初期の状態に戻るという前提で、単純に1回の走査露光毎の照射のみ考慮して投影光学系PLの透過率の変化を求めていた。しかし、紫外パルス光ILの照射停止後の回復速度によっては或るショットの露光終了後、次のショットの露光開始までに透過率が初期状態まで十分回復しないことがあり得る。特に、低感度レジストが使用されている場合には、大きな露光量を必要とするために透過率の変化が大きくなつて、ショット間で透過率が初期状態まで回復しにくくなり、投影露光装置のスループットの向上を図るためにショット間のステッピング時間等を短縮する場合にも、ショット間での透過率の回復が不十分となる恐れがあるため、紫外パルス光ILの照射停止後の透過率変動を考慮する必要がある。

【0056】そこで、本例における投影光学系PLの透過率の変化の計測動作、及び走査露光動作につき、図5のフローチャートを参照して説明する。本例では、先ず図5のステップ141～145において、第1の実施の形態のステップ101～105と同様に（第2の実施の形態のステップ121～127と同様でもよい）、紫外パルス光ILの照射中の投影光学系PLの透過率の変化を計測し、入射総エネルギー $e$ の関数としてその透過率 $T(e)$ を求めてメモリ68に記憶する。次に、ステップ147～150において、照射をしない場合の投影光学系PLの透過率の変化を計測して経過時間の関数で表す。

【0057】具体的に、ステップ146で投影光学系PLに例えば想定される最大の露光量に所定のマージンを加えた露光量が照射された状態で、ArFエキシマレーザ光源1の発光を停止する。その後、ステップ147で発光停止からの経過時間 $t$ を計測し、所定の時間間隔でステップ148において、図2のArFエキシマレーザ光源1に瞬間に最小パルス数の発光を行わせて、直接透過率計算部63において、透過エネルギー $E_o$ 及び入射エネルギー $E_i$ より投影光学系PLの透過率 $T (= E_o / E_i)$ を算出し、この透過率 $T$ を透過率演算部67に供給する。この透過率の計測を所定回数繰り返し、計測が終了したときに動作はステップ149からステップ150に移行して、透過率演算部67では、投影光学系PLの透過率 $T$ を紫外パルス光ILの発光停止からの経過時間 $t$ の関数 $T(t)$ として近似し、この関数 $T(t)$ をメモリ68に記憶する。その関数 $T(t)$ としては、予め係数を未定とした経過時間 $t$ の2次以上の関数、又は指数関数等を使用できる。

【0058】図6の曲線70Cは、紫外パルス光ILの照射停止後の投影光学系PLの透過率T (=Eo/Ei) の変化の一例を示し、この図6の横軸は照射停止からの経過時間t (hour)で、縦軸は透過率T (相対値) である。また、曲線70Aは、透過率計測用に瞬間に供給される入射エネルギーEi (相対値) を示し、曲線70Bは、その入射エネルギーEiに対応して計測される透過エネルギーEo (相対値) を示している。その曲線70Cより分かるように、紫外パルス光ILの照射停止後には、投影光学系PLの透過率Tは一度大きく回復した後、次第に低下している。メモリ68には、その曲線70Cを近似した経過時間tの関数T (t) が記憶される。

【0059】その後の走査露光時には、図1の主制御系27から図2の透過率演算部67に対して紫外パルス光ILの照射中か、又は例えばショット間のステッピング中で紫外パルス光ILの照射が中断されているかを示す情報が供給される。又は、透過率演算部67では、ADC62からの入射エネルギーEiの有無によって照射中かどうかを判定してもよい。このようにして、図5のステップ151において、透過率演算部67では、紫外パルス光ILが照射中かどうかを判定し、照射中であるときには、ステップ152において、所定の時間間隔で入射光量積分部64からの入射総エネルギーeを取り込み、ステップ153において、この入射総エネルギーe、及びステップ144でメモリ68に記憶された関数T (e) より投影光学系PLの現在の透過率T (now) を求める。そして、以下のステップ154で図3のステップ110と同様にその透過率T (now) の変化を相殺するように紫外パルス光ILの出力を制御し、以下ステップ155で走査露光が終了するまで、ステップ152～154の動作が繰り返される。

【0060】その後、ステップ155で走査露光が終了し、ステップ159で1つのショット領域への露光が終了すると、ステップ160で全部のショット領域への露光が終了したかどうかが判定され、露光が終了していないときには、ステップ151に戻る。この場合には、ウエハステージ24が次のショット領域を走査開始位置に移動するためにステッピング中であり、紫外パルス光ILの照射は中断しているため、動作はステップ151からステップ156に移行して、透過率演算部67は先ずその時点で入射光量積分部64から供給されている入射総エネルギーe、及びステップ145で記憶された関数T (e) より、現在の投影光学系PLの透過率TAを計算する。そして、次のショット領域への走査露光が始まる直前にステップ157において、透過率演算部67は、紫外パルス光ILの照射中断からこれまでの経過時間t、及びステップ150で記憶された関数T (t) より現在の投影光学系PLの透過率TBを算出する。この場合、経過時間tが0での透過率T (0) の値をTCと

すると、ステップ158において、透過率演算部67では、一例として次式より現在の投影光学系PLの実際の透過率T (now) を算出する。

【0061】

$$T(\text{now}) = TA \cdot TB / TC \quad (5)$$

そして、次のショット領域への走査露光が開始されて動作がステップ151からステップ152に移行したときには、投影光学系PLの透過率の初期値を(5)式で定まる値として、露光量制御を行う。このようにして各ショット領域への走査露光が行われ、ステップ160で全部のショット領域への露光が終了したときにステップ161で露光動作が終了する。

【0062】このように本例によれば、ショット間で紫外パルス光ILの照射が中断されている際の投影光学系PLの透過率の変動も考慮されるため、より高精度にウエハW上の各ショット領域への露光量が制御される。次に、図5の走査露光を実際にウエハW上に回路パターンを形成する工程で用いる場合の動作の一例につき、図7のフローチャートを参照して説明する。先ず、図7のステップ171において、図1のレチクルステージ20A上にレチクルRがロードされる。次のステップ172において、露光対象のウエハ (ウエハWとする) 上に金属膜を蒸着し、ステップ173において、そのウエハW上の金属膜上にレジストを塗布した後、ウエハWを図1の投影露光装置のウエハステージ24上にロードする。次に、ステップ174において、図5のステップ151～161までの動作と同様に、投影光学系PLの透過率の変化を相殺するように、即ちウエハW上の紫外パルス光ILの照度が一定となるように紫外パルス光ILの光量を制御しながら、レチクルRのパターン像を走査露光方式でウエハW上の各ショット領域に露光する。

【0063】その後、ステップ175において、ウエハW上のレジストの現像を行い、ステップ176でそのレジストパターンをマスクとしてウエハW上の金属膜のエッチングを行った後、レジストパターンを除去することによって、所望の回路パターンがウエハW上の各ショット領域に形成される。その後、ウエハWは次のレイヤの回路パターンの形成工程に移行する。この際に本例では、ウエハW上の各ショット領域で最適な露光量が得られているため、ウエハW上の各ショット領域に所望の回路パターンが高い転写忠実度で形成される。

【0064】なお、上記の実施の形態は、本発明をステップ・アンド・スキャン方式の投影露光装置に適用したものであるが、本発明はステップ・アンド・リピート方式の投影露光装置 (ステッパー) で露光する場合にも適用することができる。ステッパーの場合には、例えば図3のステップ110及び111に対応する工程で、ウエハ上の当該ショット領域への積算露光量が所定の値になるように露光時間が制御される。

【0065】なお、本発明は上述の実施の形態に限定さ

れず、本発明の要旨を逸脱しない範囲で種々の構成を取り得ることは勿論である。

#### 【0066】

【発明の効果】本発明の投影露光装置によれば、露光エネルギービームの照射開始からの投影光学系の透過率変化が照射量に応じてほぼ一定の変化量を示すことを利用して、予めこの透過率変化を計測して記憶している。そして、実際の露光時には投影光学系に入射する露光エネルギービーム量から投影光学系の透過率の変化を推定し、この透過率の変化に応じて露光量を制御しているため、投影光学系の透過率変動によって発生する基板上での照度変動（又はパルスエネルギー変動）に起因した露光量の制御精度の劣化を防止できる利点がある。

【0067】また、露光中の基板面上での露光量を計測するような新規のセンサーを追加する必要がなく、基板側のステージ付近のスペースの制約を受けることがない。この場合、透過率特性記憶部は、投影光学系の透過率の総入射エネルギー量に対する変化率の他に、露光エネルギービームの照射を中断した後の経過時間に対する投影光学系の透過率の変化率を記憶し、演算系は、透過率特性記憶部に記憶されている透過率の2種類の変化率、入射エネルギー量積算系の出力、及び露光エネルギービームの照射を中断した後の経過時間に基づいて逐次投影光学系の透過率を算出するときには、露光エネルギービームの照射の中断後に投影光学系の透過率が十分に回復しない場合でも、その投影光学系の透過率の変化を正確に推定できる。

【0068】また、本発明をステップ・アンド・スキャン方式のような走査露光方式の投影露光装置に適用した場合、走査露光方式では、投影光学系の透過率変動に応じて例えば基板面で一定の照度が得られるように露光量を制御することで、良好な露光量制御精度が得られる。次に、本発明の露光方法によれば、走査露光方式の投影露光装置を用いて、投影光学系の透過率の変化の計測時に実際にマスクを使用した状態での透過率を計測することによって、マスクのパターン密度の違いによる入射エネルギー量の変動によって投影光学系の透過率変化を誤計測することが防止され、露光量制御精度を向上させることができる。

【0069】また、本発明の回路デバイスの製造方法によれば、本発明の投影露光装置を用いて高い転写忠実度

で回路パターンを基板上に形成できる。

#### 【図面の簡単な説明】

【図1】本発明の実施の形態で使用される投影露光装置を示す概略構成図である。

【図2】本発明の実施の形態で投影光学系PLの透過率の計測を行うために、照射量モニタ32を投影光学系PLの露光領域に移動した状態を示す一部機能ブロック図を含む構成図である。

【図3】本発明の第1の実施の形態における投影光学系PLの透過率計測動作、及び露光動作を示すフローチャートである。

【図4】本発明の第2の実施の形態における投影光学系PLの透過率計測動作、及び露光動作を示すフローチャートである。

【図5】本発明の第3の実施の形態における投影光学系PLの透過率計測動作、及び露光動作を示すフローチャートである。

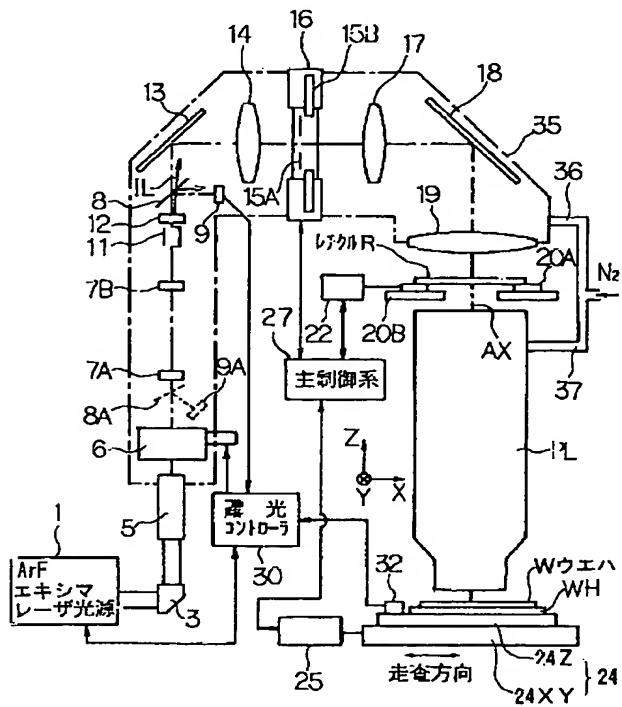
【図6】その第3の実施の形態で計測される紫外パルス光の照射停止以後の投影光学系PLの透過率の変化の一例を示す図である。

【図7】その第3の実施の形態において回路パターンを形成する工程の一例を示すフローチャートである。

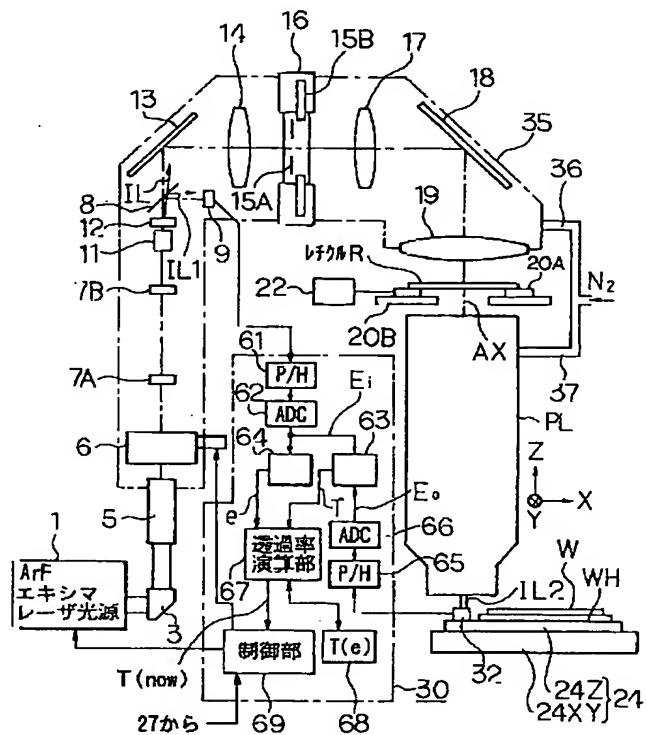
#### 【符号の説明】

- 1 ArFエキシマレーザ光源
- 11 フライアイレンズ
- 8 ビームスプリッタ
- 9 インテグレータセンサ
- 16 レチクルブラインド機構
- R レチクル
- PL 投影光学系
- W ウエハ
- 20A レチクルステージ
- 24 ウエハステージ
- 27 主制御系
- 30 露光制御ユニット
- 32 照射量モニタ
- 63 直接透過率計算部
- 64 入射光量積分部
- 67 透過率演算部
- 68 メモリ
- 69 制御部

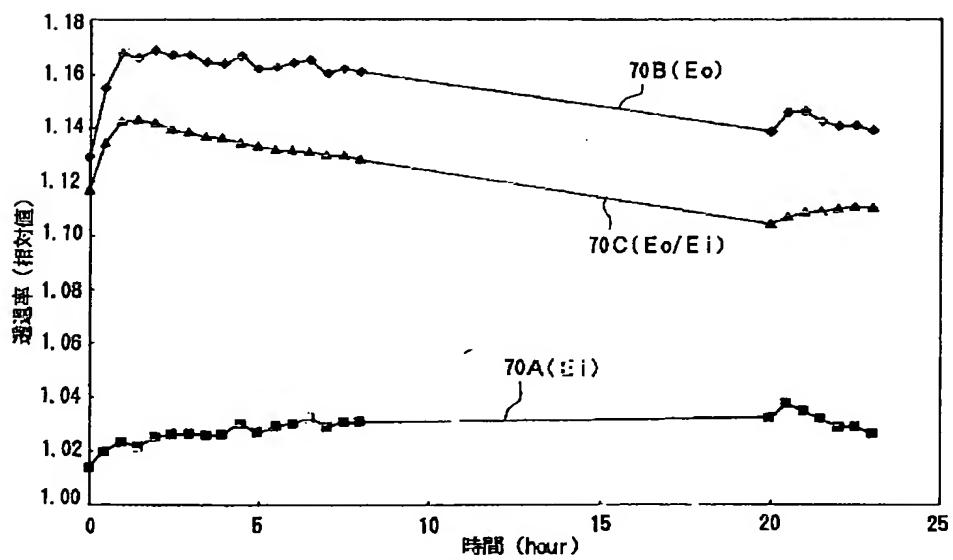
【図1】



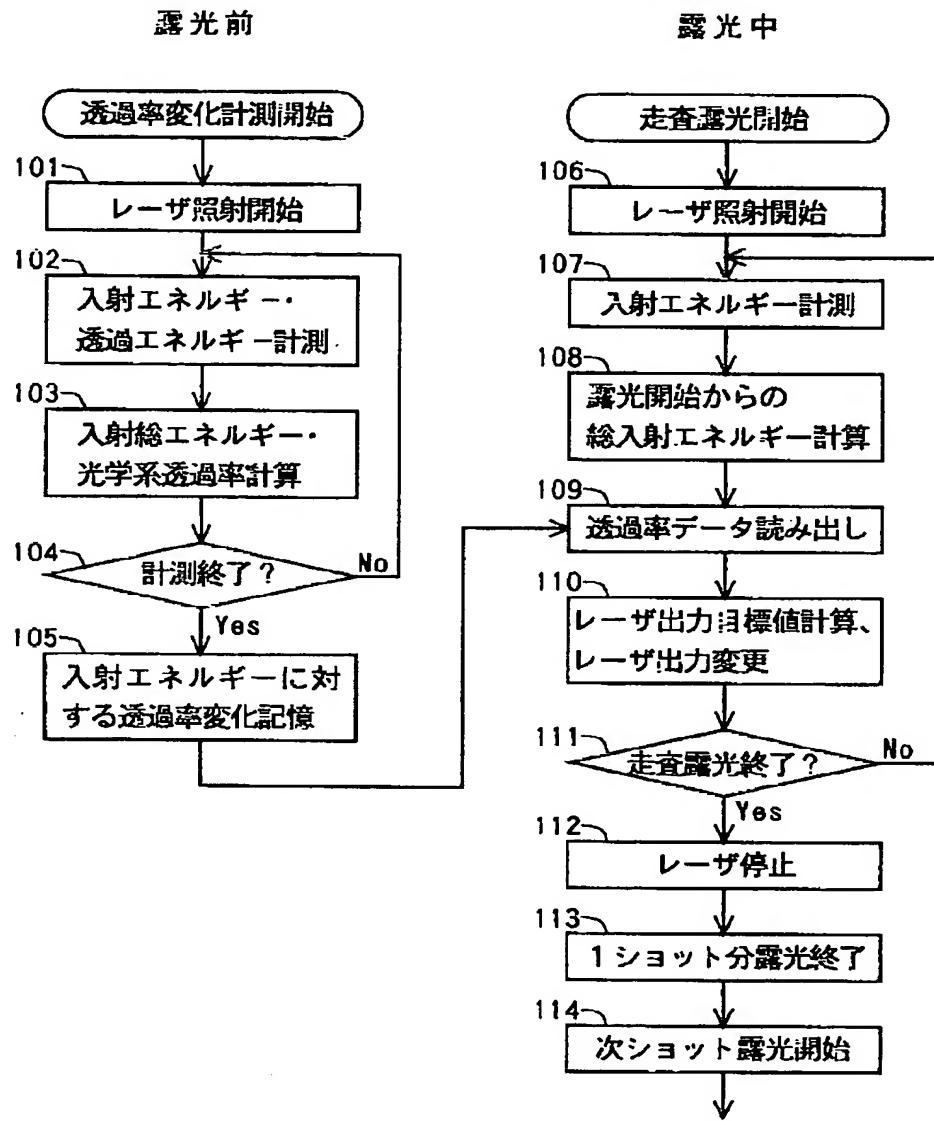
【図2】



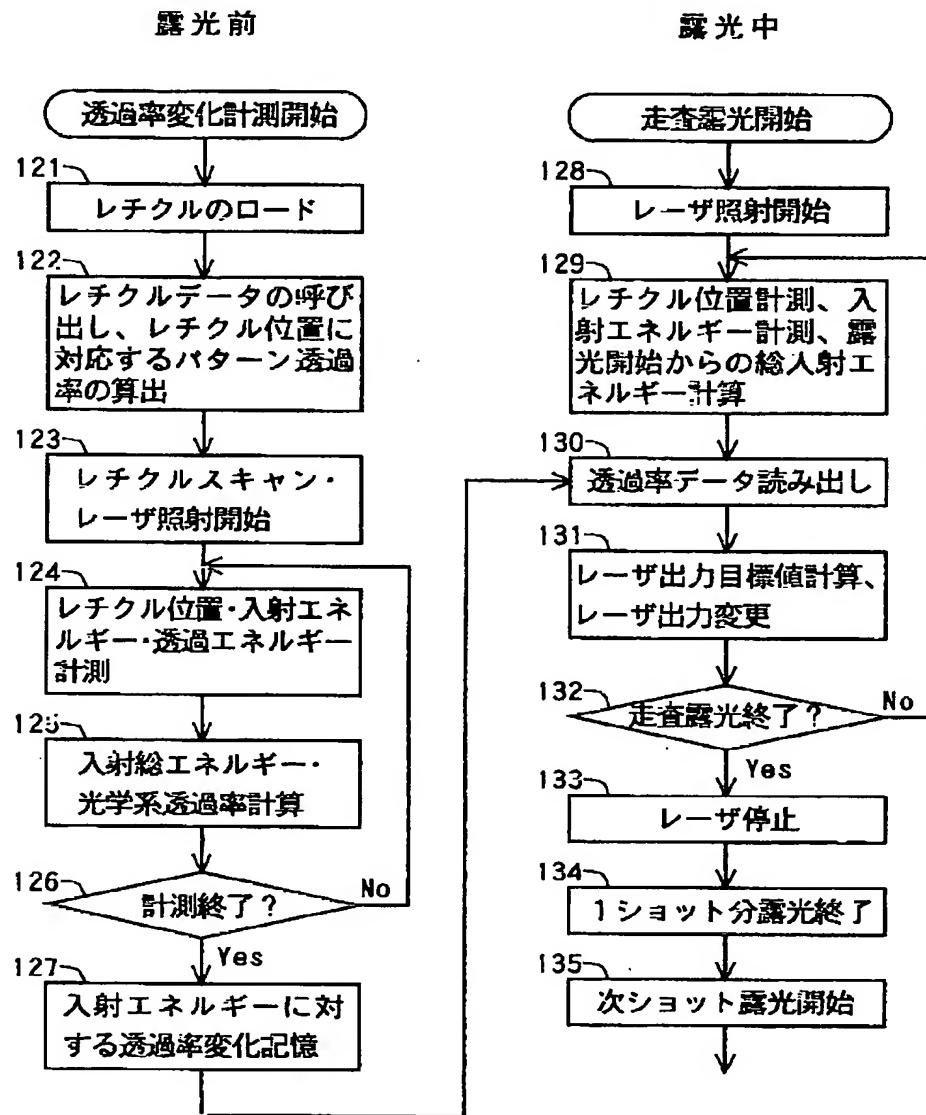
【図6】



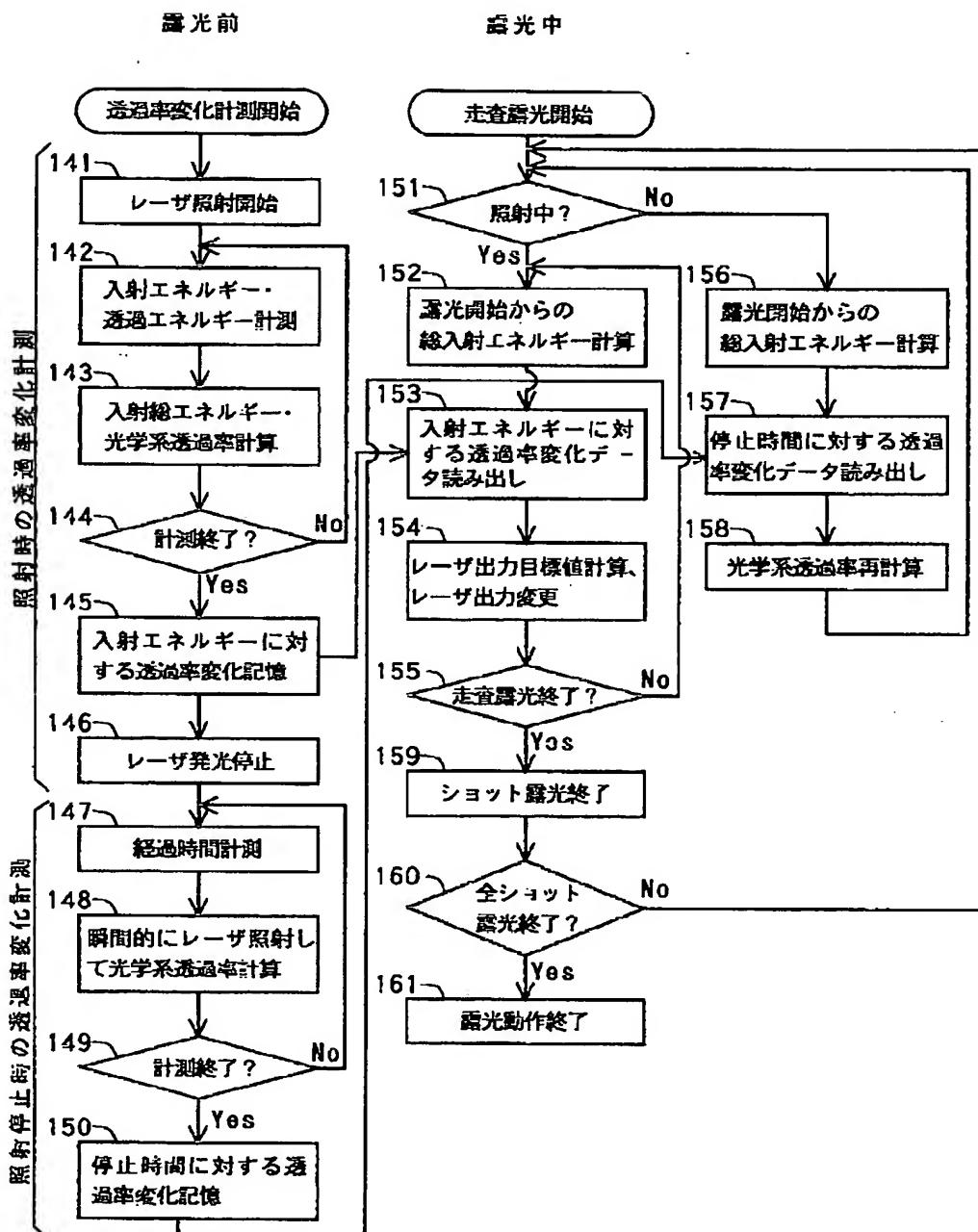
【図3】



【図4】



【図5】



【図7】

